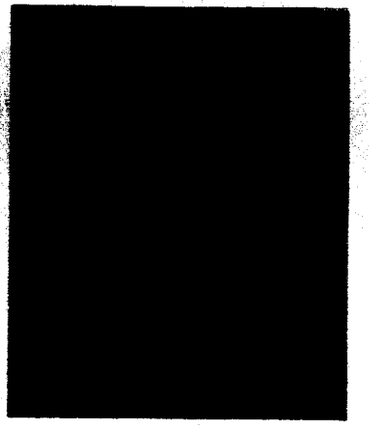
120 p.

UNPUBLISHED PRELIMINARY DATA
N63 22883
CODE-1
NASA CR 51934



BOOZ · ALLEN APPLIED RESEARCH, INC.

OTS PRICE

XEROX $ 9.60 ph

MICROFILM $ 3.60 mf.

OTS: $3.00 ph, $1.50 mf

(NASA CR 51824)

OPERATIONS ANALYSIS OF INTEGRATION, CHECKOUT AND LAUNCH OF SPACE VEHICLES.

DELTA VEHICLE GENERAL EVALUATION APPROACH,

[PART I] VOLUME I

LAC 75
B

Prepared for

Office of Space Sciences, Launch Vehicles and Propulsion,
National Aeronautics and Space Administration

by

129759

Booz-Allen Applied Research, Inc.
Bethesda, Maryland

Under
(NASA Contract NASw-758)

H. S. Barton et al

September 30, 1963, 828-2-1

31 pp

BOOZ•ALLEN APPLIED RESEARCH INC.

WASHINGTON
CLEVELAND
CHICAGO

FOREWORD

This study was conducted for the National Aeronautics and Space Administration by Booz, Allen Applied Research Inc., Bethesda, Maryland, under Contract NASw-758. It represents the first part of a three part study on the integration, checkout and launch procedures used for space vehicles. The first part of the study was concerned with the Delta vehicle and with formulating a general approach for use in investigating other vehicle programs in greater detail. The second and third parts, which will be described in later reports, are to be concerned with the Atlas-Agena program, and with planning an optimum program for a hypothetical vehicle, respectively.

This Part I report is divided into two volumes; Volume I contains the Delta vehicle results, with the exception of the Delta cost analysis, and a discussion of the general approach. Volume II, which is separately bound, contains only the Delta Cost Analysis; Appendix A of this report.

The Booz, Allen Applied Research personnel who performed this study and contributed to this report were K. S. Barten, A. C. Johnson, W. J. Neff, A. Pickens, Dr. W. P. Sommers and J. B. Truett.

TABLE OF CONTENTS

		Page Number
	VOLUME I	
INDEX OF TABLES		iv
INDEX OF FIGURES		v
SUMMARY		vi
I.	INTRODUCTION	1
II.	REVIEW OF DELTA PROGRAM	4
1.	Program History	4
2.	Vehicle System Description	7
3.	Integration, Checkout and Launch Sequence	11
III.	ANALYSIS OF DELTA LAUNCH OPERATIONS	22
1.	Checkout and Launch Schedules	24
2.	Unscheduled Activities Analysis	34
3.	Redundancy in Testing and Checkout Procedures	60
IV.	RESULTS APPLICABLE TO FUTURE STUDIES	67
1.	Problem Definition	67
2.	Analytical Cost Model	72
3.	Information and Data Required	90
V.	CONCLUSIONS AND RECOMMENDATIONS	95
1.	Delta Program	95
2.	Future Studies and Programs	101
REFERENCES		104
BIBLIOGRAPHY		106
	VOLUME II	
APPENDIX A: DELTA COST ANALYSIS		

INDEX OF TABLES

Table		Page Number
1	Delta Mission Summary	6
2	Typical Delta Vehicle Preparation and Test Schedule	15
3	Delta Vehicle - Time at AMR	25
4	Actual Delta Vehicle Time Spans	27
5	Missed Launches - Delta Vehicle	33
6	Delta Vehicle - Average Occurrence of Unscheduled Activities and Critical Faults per Test Phase	38
7	Delta Vehicle - Distribution of Unscheduled Activities and Critical Faults by Test Phase for Individual Launches	39
8	Delta Vehicle - Distribution of Unscheduled Activities by Probable Cause	40
9	Delta Vehicle - Malfunctions and Sub-Standard Items Believed to have Originated at the Factory	42
10	Delta Vehicle - Distribution of Unscheduled Activities by Vehicle Stage	43
11	Delta Vehicle - Distribution of Critical Faults Stage I vs. Stage II	44
12	Delta Vehicle - Distribution of Unscheduled Activities and Critical Faults by Systems	46
13	Delta Vehicle - Test Observations Related to Redundant Aspects of T-6 Day and T-3 Day Procedures	63

INDEX OF FIGURES

Figure		Page Number
1	Comparison of "Typical" Delta Vehicle Launch Schedule to Average Experienced Start of Pre-Composite Test Through Launch	29
2	Delta Vehicle - Time to Launch (From Start of Pre-Composite Test)	30
3	Number of Unscheduled Activities and Critical Faults vs. Total Booster Stay at AMR	47
4	Delta Vehicle - Unscheduled Activities and Critical Faults for Period from Start of Pre-Composite Test to Launch vs. Time Required	48
5	Delta Vehicle - Unscheduled Activities and Critical Faults vs. Flight Number	49
6	Delta Vehicle - Unscheduled Activities vs. Flight Number Classified According to Probable Cause	50
7	Delta Vehicle - Malfunctions and Sub-Standard Items Believed to Have Originated at the Factory	51
8	Unit Launch Costs as a Function of Launching Rate (Assuming Basic Crew and Facilities are Adequate for the Maximum Launching Rate)	75
9	Unit Launch Costs as a Function of Launching Rate (Launch Rate Increases Beyond Basic Capabilities)	76
10	Variation of Costs with Failure Probability	81
11	Effect of Investment Policy Upon Total Costs per Launch	86
12	Effect of Turn-Around Time Upon Total Costs per Launch	87

SUMMARY

As the prevenient step in a three phase operations analysis of space vehicle integration, checkout and launch procedures, the Delta vehicle program is reviewed and analyzed. The conspicuous success of the Delta program (19 successful launches out of 20 attempts) could not be accounted for by any single factor, but rather was concluded to be the combined result of diligent efforts in construction and checkout, use of proven, conventional stages and experienced personnel, and the presence of virtually daily launch "windows".

External constraints of mission scheduling, payload availability, and associated funding control the checkout and launch aspects of the Delta program, not the technical proficiency of personnel or equipment used. A launch rate of 24 Delta vehicles per year is believed attainable, utilizing only existing facilities and procedures, but is not required under the current external constraints. Major improvements and recommendations for significant changes are therefore inappropriate. Recommendations for improvements are made in case circumstances in the future require their use. In the same respect, it is concluded a higher launch rate could result in lower costs per launch, but no such option exists under present Delta mission plans.

A review of previous Delta launches and checkout histories disclosed that the number of unscheduled activities encountered during checkout and launch was independent of vehicle total storage time at AMR, and that little, if any, trend was apparent that showed such activities either decreasing or increasing with the Delta flight number. The checkout and launch procedures were found, to a large degree, to accomplish their purpose.

The Delta investigation has been utilized to refine the scope and objectives of the required study, to outline the data and information which must be assembled to accomplish the task, and to initiate the construction of an analytical cost model. The cost model is to be used to relate the factors which determine the cost per launch of a vehicle, to determine the optimum launch rate, and to aid in the evaluation of program management decisions. Further efforts in this regard are expected to materially aid program planning and project management activities.

I. INTRODUCTION

The total cost of integration, checkout and launching of a space vehicle is of the same order of magnitude as the cost of the vehicle on many current launch programs. For example, in the Atlas-Agena program it is estimated these functions cost close to $\$3 \times 10^6$ per launch, out of a total cost of $\$7.5 \times 10^6$ per launch. The launch, hangar, and checkout facilities required to perform these tasks necessitate multi-million dollar expenditures. Thus, it is of considerable potential value to study the way launch and checkout functions are performed, to investigate the utilization and suitability of the equipment involved, and to determine the cost of the major factors. This report constitutes the results of the first step in such a study.

The aim of this investigation is: to determine and recommend procedural and equipment improvements, where appropriate; to minimize the cost and improve the performance of integration, checkout and launch operations; and to develop an analytical cost model which will predict the cost relationships of these operations, determine costs per launch, and be useful as a management tool for planning purposes.

The scope of the study starts at the completed assembly of the launch vehicle stages, as they leave the production line, and extends to the successful injection of the payload into the intended orbit or escape trajectory. The study therefore includes all operations which occur between these two events, including the factory checkout, transportation, the hangar checkout, the integration activities, and the actual launching. It is equally concerned with the equipment required to perform these jobs. An important aspect of the work is the development of an analytical cost model to describe the cost relationships of the factors encompassed by the study. This cost model is to be used to determine current costs per launch, to compute optimum launch costs and launch rates, to understand the cost/process/reliability relationships, and to aid in planning future programs.

This report covers the first part of a three part study which was initiated June 5, 1963. As such it contains all of the results from the Delta study and a description of the knowledge acquired which is applicable for use in the next two parts. The next step in the study is to be concerned with the Atlas-Agena vehicle, which will be studied in significantly more detail than was Delta. The third step will utilize the information acquired in the first two steps to recommend plans and procedures to be followed in the optimum development of a hypothetical vehicle.

To accomplish the work reported herein, reports were obtained from Douglas and NASA which describe the vehicle, the checkout procedures (especially those concerned with T-6 day to launch) and some of the payloads. Ground and flight test reports were obtained for most of the twenty Delta flights. Several visits were made to the Atlantic Missile Range, a visit was made to the Western Operations Office of NASA, and another to the Douglas Aircraft Company, Santa Monica, California. The preparation, checkout and launch of Delta 20, carrying the Syncom II satellite, were followed closely at AMR. Discussions were held at AMR with Douglas and NASA field personnel (GSFC - Field Projects Branch). Additional information and cost data were obtained from NASA Headquarters.

II. REVIEW OF DELTA PROGRAM

The Delta program is a four year old project which was initiated for the launching of NASA scientific spacecraft, weighing up to approximately 800 pounds. The vehicle was formulated of three existing stages, all of whose major systems and subsystems had undergone a dozen or more (in some cases, many more) flight tests. It has been a highly successful program, achieving 19 successes out of 20 launch attempts, the first attempt being the only launch failure.

1. PROGRAM HISTORY

Delta is a three-stage spacecraft launch vehicle developed by Douglas Aircraft Company (DAC) for the National Aeronautics and Space Administration (NASA) (Reference 1). Stage 1 is a modified Douglas Thor missile; Stage 2 is an Aerojet General Corporation (AGC) liquid propellant rocket with a Douglas-built guidance system compartment; Stage 3 is a Naval Propellant Plant (NPP) solid rocket motor. Payloads are under the control of the Goddard Space Flight Center (GSFC). Mission capability is approximately 800 pounds injected into a 350 nautical mile altitude circular orbit, or 120 pounds accelerated to earth escape velocity.

The initial development contract for 12 Delta launch vehicles was awarded to Douglas in May 1959. Elements of the Thor-Able and Vanguard Programs were to be incorporated into an interim vehicle. The first Delta launch took place on May 13, 1960. The launch was unsuccessful in that the 3rd stage did not ignite. Following a period of effort in design checks, quality control improvements and environmental tests, the second Delta launch took place on August 12, 1960, successfully placing the Echo I passive communications satellite into orbit. The remaining 10 vehicles in the first development contract all achieved successful spacecraft orbits. A second block of 14 vehicles was ordered from Douglas and a number of spacecraft launch projects were shifted from other, less successful vehicles. The first vehicle in the second block was launched October 2, 1962, and the first of an improved model (No. 15), was launched December 13, 1962. Through August 1963 a total of 20 Deltas have been launched; of these 19 (all except No. 1) have achieved successful spacecraft orbits. This record of 19 out of 20 (95 per cent) has been equalled only by the man-carrying Atlas-Mercury vehicles. Since the intensive quality upgrading effort that was instigated after Delta flight No. 1 has apparently eliminated a problem that would have existed otherwise, the effective reliability of Delta is 100 per cent. A summary of Delta missions, with launch dates and payloads, is given in Table 1.

Table 1
Delta Mission Summary

Delta	Satellite	Date Launched
		1960
1	Echo (failed to orbit)	May 13 (3rd stage did not ignite)
2	Echo 1	August 12
3	Tiros II	November 23
		1961
4	Exporer X (P-14)	March 25
5	Tiros III	July 12
6	Explorer XII (5-4)	August 16
		1962
7	Tiros IV	February 8
8	OSO-1	March 7
9	UK-1	April 26
10	Tiros V	June 19
11	Telstar I	July 10
12	Tiros VI	September 18
13	Explorer XIV	October 2
14	Explorer XV	October 27
15	Relay I	December 13
		1963
16	Syncom I	February 14
17	Explorer XVII (S-6)	April 2
18	Telstar II	May 7
19	Tiros VII	June 19
20	Syncom II	July 26

All NASA Delta missions have been launched from the Atlantic Missile Range (AMR), utilizing launch Pads 17A and 17B (originally the Thor missile development launch pads). The vehicle integration, checkout, and launch countdown is carried out by DAC personnel at AMR under a separate NASA contract, and monitored and directed by the GSFC Field Projects Branch (FPB).

A third block of 14 vehicles has been ordered by NASA, bringing the total to 40 vehicles. Development of expanded mission capability is being proposed by Douglas, as well as studies of new vehicle configurations. It appears Delta will continue in use for launching meteorological, communication and scientific payloads.

2. VEHICLE SYSTEM DESCRIPTION

An excellent description of the Delta vehicle is contained in the Douglas report, Reference 1. A brief summary of those facts found useful in interpreting some of the checkout and launch procedures is presented in the following.

(1) First Stage

The first stage of the Delta vehicle in its present configuration is a modified Douglas DM-21 Thor booster. The first stage is manufactured by the Douglas Aircraft Co. on the Thor

booster assembly line. It is a modification of one of the basic Thor configurations, the modification being accomplished in the same building in which it is assembled.

The first stage is stabilized and controlled by gyro signals and shaping networks responsive to commands from the guidance system in the second stage; fixed fins are added to increase aerodynamic stability.

(2) Second Stage

The second stage of the Delta vehicle incorporates an Aerojet General Corporation propulsion system, a Douglas flight control, guidance and electronics section, and houses the on-board equipment of the Bell Telephone Laboratory (BTL) Series 600 radio guidance system. Steering commands received by the vehicle from the ground-based computer are sent to the first or second stage flight controller. The flight controller and propulsion system are designed and operated to provide back-up mission capability in case of a BTL guidance failure (this capability was successfully used on Delta 10).

(3) Third Stage

The third stage of the Delta vehicle is powered by a solid propellant rocket motor developed by the Alleghany Ballistics Laboratory, currently manufactured by the Naval Propellants Plant and designated the X248-A5. The third stage is spin-stabilized prior to ignition by firing spin rockets on the spin-table attached to the second stage. The third stage is non-controllable and unguided. The third stage includes the motor and supporting structure, the payload attach fitting, and the aerodynamic fairing, which is jettisoned during second stage burning.

(4) Interstage and Fairing Structure

Interstage structures connect the three stages of the Delta vehicle. The first and second stages are joined by a truss structure. The second to third stage interstage structure consists of a spin-table on which the third stage motor support structure is mounted. The payload attach fitting is mounted directly on the third stage motor.

During the ascent through the atmosphere, the third stage and spacecraft are protected by aerodynamic fairings which are jettisoned during second stage burning by explosive-bolt-released

springs. These fairings are made in two configurations, bulbous for large spacecraft, and streamlined for maximum performance. The fairings are constructed of phenolic fiberglass and may include additional insulation.

(5) Payload Capability

Maximum payload capability of the Delta system is dependent on orbit requirements, and is somewhat restricted by limitations on launch direction (azimuth) at AMR. For nominally circular orbits, the following relation of orbit altitude and payload weight exists for the present capability of the system (Reference 1):

800 pounds at 350 n. miles

600 pounds at 500 n. miles

400 pounds at 780 n. miles

300 pounds at 1100 n. miles

Payload preparation, at both the factories and at AMR, is kept separate from vehicle preparation until the RF compatibility tests about 10 days before launch. However, payload and mission requirements are carefully considered in determining the vehicle preparation, including special equipment,mission control tapes,

and launch window limitations. Because of its outstanding success in orbiting small payloads, additional capability is being added to the Delta vehicle so that larger payloads can be launched.

(6) Launch Facility

The launch facility for the Delta vehicle is located at the Atlantic Missile Range (AMR). Delta uses launch Complex 17 at Cape Canaveral, with two pads. Pads 17A and 17B are water cooled. The gantry structure rolls back on tracks during certain tests and when the vehicle is ready for firing. Checkout can be accomplished simultaneously on both pads. Launch operations are controlled from a blockhouse in the launch complex. During vehicle preparation and checkout the payload/3rd stage area is enclosed in a tent or plastic weather protection with air conditioning supplied.

3. INTEGRATION, CHECKOUT AND LAUNCH SEQUENCE

The sequence of operations covering the period from vehicle manufacture to spacecraft injection into orbit can conveniently be divided into the following segments:

(1) Factory Checkout

(2) AMR Integration and Checkout Activities

(a) AMR Hangar Activities
(b) Launch Pad Operations

The over-all sequence of segments (1) and (2) above, as applied to the Delta vehicle, has been outlined in DAC charts and manuals (see References). The following description is based upon these charts and manuals, supplemented by discussions with DAC and NASA personnel.

(1) Factory Checkout

The Delta vehicle is shipped to AMR as separate 1st, 2nd and 3rd stages, with interstage hardware and fairing.

The 1st stage (booster) is assembled on the Air Force Thor missile final assembly line at DAC Santa Monica. The Air Force then checks the vehicle and buys it from Douglas. NASA buys the vehicle from the Air Force and gives it back to Douglas for modification to the Delta configuration. A few of the basic Thor components are changed during the modification, but most systems and components are left at Air Force specification levels. (NASA indicates these are lower standards than those used in Delta.) Checkout is primarily by manual techniques, and is accomplished on the assembly line in one of two check stands.

The 2nd stage is manufactured in three different sections. The propulsion section is built by Aerojet General and shipped to DAC Santa Monica. The compartment for guidance and electronics systems is built at DAC Tulsa and shipped to Santa Monica. DAC Santa Monica mates the propulsion stage and the electronic equipment compartment, and then squares off the front end very accurately for alignment of the spin table which supports the 3rd stage. The guidance, control, and other electronics equipment is then installed in the stage.

The completed 2nd stage is checked out in a separate test room. Checkout is primarily by manual procedures with limited use of system simulators. Checkout follows a written procedure, which appears to be very straightforward. Important parameters may be reset to nominal value, even if within tolerance; other parameters which check within tolerances are generally okayed. The checkout of the 2nd stage takes about a week, if no problems are uncovered.

Douglas maintains a philosophy of very high quality control. Circuits which are suspect may be completely replaced, even if simpler repairs can be made. This philosophy is also reflected in the EHR (extra high reliability) program

applied to semiconductors. The EHR program is a 100 per cent test quality control program instituted because of known deficiencies in transistors normally received from vendors.

A number of engineering modifications may also be installed at the factory. These result primarily from feedback from flight results. NASA desires all modifications to be installed in all vehicles.

The 3rd stage is not checked out at the DAC factory, but rather is shipped directly from the Naval Propellant Plant to AMR (3rd stage rocket motor is fueled with double base propellant, and thus is an explosive). The payload fittings and interstage structure are attached at AMR.

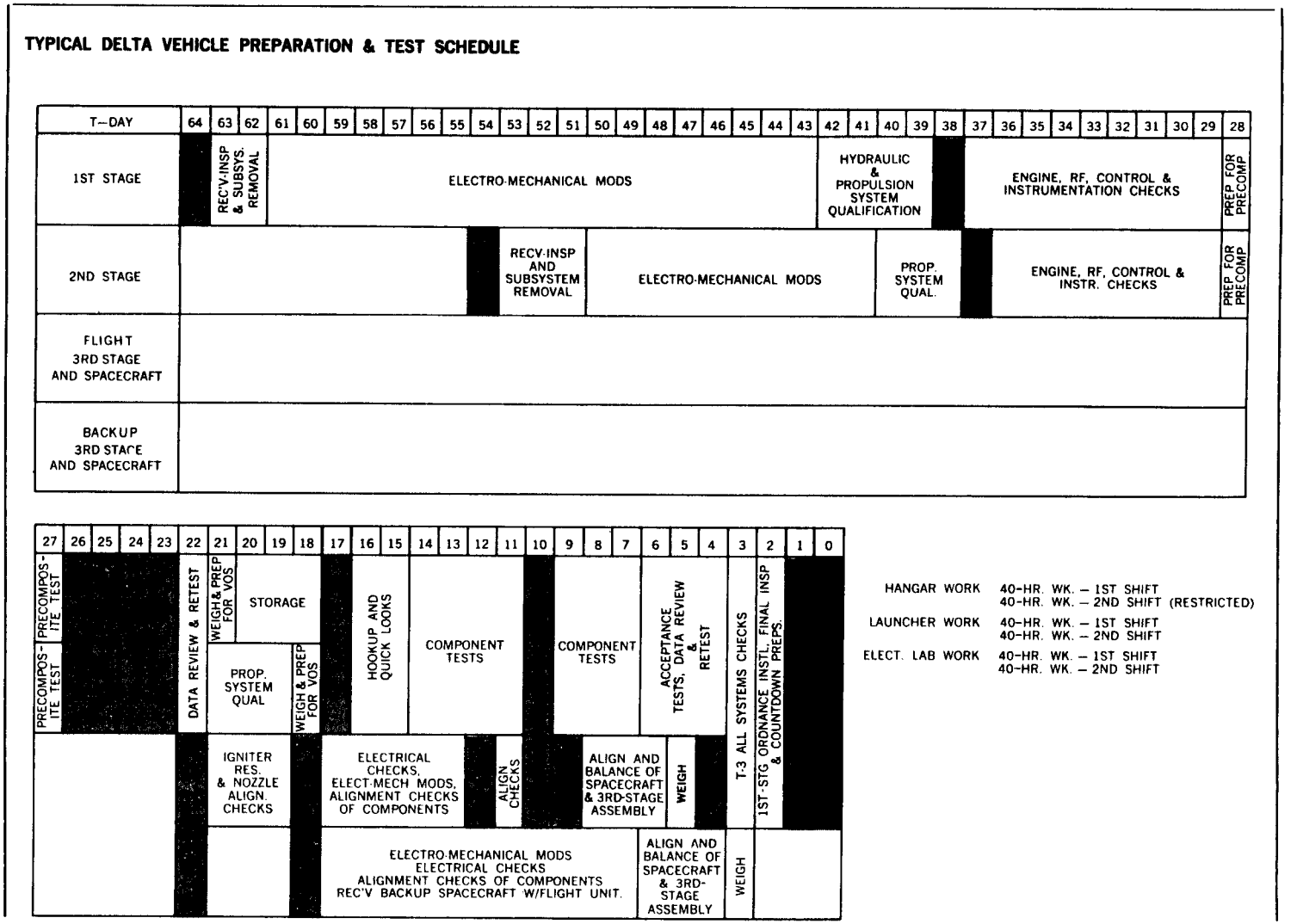
Douglas indicates that the 1st and 2nd stages are complete and "perfect" when delivered to Cape Canaveral but often engineering mods will be held until after arrival at AMR.

(2) AMR Integration and Checkout Activities

The basic procedure for integration and checkout of the vehicle is outlined in the Douglas "Typical Delta Vehicle Preparation and Test Schedule", Table 2. Complete systems and component checks of the booster and 2nd stage are performed in

TABLE 2

TYPICAL DELTA VEHICLE PREPARATION & TEST SCHEDULE
OBTAINED FROM DOUGLAS DOCUMENT SM-43616 (REFERENCE 1)


TYPICAL DELTA VEHICLE PREPARATION & TEST SCHEDULE
T–DAY
64 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28
1ST STAGE
RECV-INSP & SUBSYS. REMOVAL
ELECTRO-MECHANICAL MODS
HYDRAULIC & PROPULSION SYSTEM QUALIFICATION
ENGINE, RF, CONTROL & INSTRUMENTATION CHECKS
PREP FOR PRECOMP
2ND STAGE
RECV-INSP AND SUBSYSTEM REMOVAL
ELECTRO-MECHANICAL MODS
PROP. SYSTEM QUAL.
ENGINE, RF, CONTROL & INSTR. CHECKS
PREP FOR PRECOMP
FLIGHT 3RD STAGE AND SPACECRAFT
BACKUP 3RD STAGE AND SPACECRAFT
27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
PRECOMPOS-ITE TEST
PRECOMPOS-ITE TEST
DATA REVIEW & RETEST
WEIGH & PREP FOR VOS
STORAGE
PROP. SYSTEM QUAL
WEIGH & PREP FOR VOS
HOOKUP AND QUICK LOOKS
COMPONENT TESTS
COMPONENT TESTS
ACCEPTANCE TESTS, DATA REVIEW & RETEST
T-3 ALL SYSTEMS CHECKS
1ST-STG ORDNANCE INSTL, FINAL INSP & COUNTDOWN PREPS.
IGNITER RES. & NOZZLE ALIGN. CHECKS
ELECTRICAL CHECKS, ELECT-MECH MODS, ALIGNMENT CHECKS OF COMPONENTS
ALIGN CHECKS
ALIGN AND BALANCE OF SPACECRAFT & 3RD-STAGE ASSEMBLY
WEIGH
ELECTRO-MECHANICAL MODS ELECTRICAL CHECKS ALIGNMENT CHECKS OF COMPONENTS REC'V BACKUP SPACECRAFT W/FLIGHT UNIT.
ALIGN AND BALANCE OF SPACECRAFT & 3RD-STAGE ASSEMBLY
WEIGH
HANGAR WORK 40-HR. WK. – 1ST SHIFT
40-HR. WK. – 2ND SHIFT (RESTRICTED)
LAUNCHER WORK 40-HR. WK. – 1ST SHIFT
40-HR. WK. – 2ND SHIFT
ELECT. LAB WORK 40-HR. WK. – 1ST SHIFT
40-HR. WK. – 2ND SHIFT

the hangar, the two stages are then mated electrically for a dual composite test, and finally erected and completely mated on the launch stand (VOS). The extensive on-stand procedure includes erection of a third stage with inert motor and prototype payload for RF interference checks on T-10 day, a 1st and 2nd stage acceptance test on T-6 day, erection of the flight 3rd stage and payload for an all-systems test on T-3 day, and launch countdown starting on T-1 day.

The entire sequence from receipt of the launch vehicle at AMR to launch nominally takes about twelve weeks. Weekend work is scheduled if necessary to catch up lost time or correct extensive problem areas. The typical sequence of operations at AMR is given in Table 2 (all days are designated as working days prior to launch, T-1 etc.). The over-all sequence is intentionally designed to be "loose" so that difficulties in one step will not necessarily be reflected as a launch delay.

(a) AMR Hangar Activities

The Delta first stage and second stage vehicles spend most of their time at AMR in the DAC hangar area. After receiving inspection, the vehicles are modified as necessary to meet engineering orders (EO's) which may accompany the vehicle from Santa Monica, or which have been authorized after the vehicle has been shipped. Each

of the systems is checked out thoroughly. These checks repeat the checkout procedures accomplished at DAC Santa Monica, plus tests which cannot be done at the factory such as RF checks. With the philosophy of EHR in mind, acceptance of systems and components by DAC-AMR personnel may differ slightly from that at DAC Santa Monica since either group may not be satisfied with some component. In the typical vehicle preparation procedure, the above operations take about seven weeks for the 1st stage and five weeks for the 2nd stage.

After completion of scheduled modifications and checkout for each stage, a pre-composite test is accomplished on each stage. The vehicles are then electrically mated in the hangar ("grid area") and a dual composite test is carried out. Satisfactory completion of this test, with rechecks to clear up problem areas, is the indication that the vehicle is ready to be delivered to the launch pad. (1st and 2nd stages are moved separately.)

The 3rd stage and payloads follow a much different route at AMR (Reference 2). Their sequence begins about the time of the dual composite test on the 1st and 2nd stages (T-5 weeks). The 3rd stage rocket motor is kept in the propellants storage area at AMR where limited checks of the ignition system are carried out. The motor is then sent to the spin-balance facility, remote from the other areas for safety purposes, for alignment, stage-build-up and balancing.

The interstage structures and fairing are received at the DAC hangar area, modified if necessary, and checked out before being sent on. The payload attach fitting, 3rd stage support structure, spin table and fairing proceed from the hangar to the spin-balance area. The 1st and 2nd stage transition and interstage structures go directly from the hangar to the launch pad.

In order to have a complete electrical system for carrying out an RF compatibility (interference) test ten days before launch, the prototype spacecraft, which is electrically identical to the flight model, is mounted on an

inert 3rd stage motor, and this assembly mated to the 1st and 2nd stage on the stand. After the RF tests, the prototype spacecraft is demated.

The flight model spacecraft arrives at the spacecraft lab in NASA Hangar AE about three weeks prior to the scheduled launch date for its own checkout procedure (conducted by the spacecraft contractor). When checkout in the spacecraft lab is completed, the spacecraft is transferred to the spin-balance facility, nominally nine workdays before launch.

In the spin-balance facility, the alignment of the 3rd stage motor is checked, then the motor is aligned with the spin-table and supporting structure. This assembly may be balanced at this time, or after spacecraft attachment. In either case, the spacecraft is attached to the 3rd stage motor using the spacecraft attach fitting, and a fit check is made of the fairing. Then the entire 3rd stage (without fairing) is dynamically balanced on the balance jig. The purpose of this is to insure the proper trajectory during the spin-stabilized period of flight. The balanced 3rd stage assembly is then put in a special handling container and delivered to the launch pad. The complete sequence of operations in the spin-balance facility is about four or five days, so that the 3rd stage is ready for mating to the launch vehicle on the pad about T-5 or T-4 day.

The spacecraft is given a daily functional test throughout the entire time it is at AMR. These checks of spacecraft functions are intended to insure that all systems and components are in good order. Duration of the daily tests is about one hour.

The completion of hangar work is about T-18 (days) for the 1st and 2nd stages, and T-5 for the 3rd stage with payload. Further checkout and countdown is accomplished on the launch pad.

(b) Launch Pad Operations

The 1st and 2nd stage vehicles are transported separately to launch complex 17 for erection on pad 17A or 17B, about T-17 to T-15 days; (see typical "Launcher Operations Schedule", Reference 3). The vehicles are erected using the gantry crane (2-3 hours each stage), utilities are hooked up and "quick look" checks are made. The two stages may be erected the same day, but the 2nd stage may be delayed a day or two, in which case the gantry is secured around the 1st stage. Leak checks of the 1st stage propulsion system, and 2nd stage electrical checks are carried out on T-14 to T-12.

In preparation for the RF interference tests, the prototype spacecraft, assembled to an inert 3rd stage motor, is mated to the vehicle about T-11. First stage electrical checks are also begun.

The RF interference tests are conducted on T-10 day. Configuration includes the prototype spacecraft which is supposed to be electrically identical with the flight model spacecraft.

The main purpose of the tests is to insure compatibility of the launch vehicle and spacecraft with all the sources of RF emission which will be used during the checkout, count-down and launch. This includes range radars, telemetry, guidance and command systems and communications. The RF radiation from these sources might introduce spurious signals in the command and control circuits of the space-craft or launch vehicle and thereby interfere with proper operation. During tests, all RF sources are activated to produce the combined RF environment that might be encountered during actual checkout and launch.

The RF interference tests serve a secondary purpose of indicating the effects of the fairing and gantry on RF signals emitted from the spacecraft and launch vehicle. This information is useful since both the fairing and the gantry could attenuate signals from the spacecraft and Delta transmitter, and since some pre-launch checkouts and tests are conducted with either the fairing or the gantry,

or both, surrounding the launch-vehicle. Tests are run with the gantry both forward and removed. For some spacecraft, RF tests may be run with the fairing both on and off, but the fairing-off tests are often eliminated. The duration of the RF tests is about two hours. The prototype spacecraft is removed immediately after the RF tests.

Electrical checks on 1st and 2nd stages continues on T-9 to T-7. The launch vehicle acceptance test is carried out on T-6 (Reference 4). This is a simulated launch, and it is an important test. All vehicle systems are checked for proper operation on both external and internal power, all electrical circuits are actuated in sequence, and the guidance system follows a taped "mission" sequence. The test follows a real-time check-off procedure. Telemetry and visual read-outs are made. The test duration is about three hours, and involves coordination with range facilities, such as tracking radars.

Leak tests of the 2nd stage are performed on T-5, and some electrical systems checks are re-run.

The flight model spacecraft and 3rd stage assembly is mated to the launch vehicle on T-4. The spacecraft/3rd stage is hoisted in its handling container. After mating the stages, the 3rd stage motor is air conditioned continuously until launch.

With the entire vehicle complete, the All-Systems Test is run on T-3 day (Reference 5). This is pretty much a repetition of the T-6 acceptance tests, but with the spacecraft in the system. Again, the tests are run on both external and internal power. (Internal power is supplied by back-up batteries and not the flight batteries, which are being recharged.) The T-3 day tests take about two hours. Successful completion of these tests is the signal for final launch preparation. Ordnance installation and facility checks are carried out on T-2.

The countdown for launch of the Delta vehicle involves two distinct procedures; one for T-1 day, and one for T-0 day. These procedures are given in summary form and in detail in the countdown manual (Reference 6). This

document is a real-time procedure telling who does what, when. Countdown procedures are also summarized in the Operations Summary prepared by NASA before each launch (e.g., References 7 and 8). Primary tasks of the T-1 countdown are vehicle and spacecraft functional checks and 2nd stage fueling. Primary tasks of the T-0 countdown are 1st stage fueling, ordnance checks and arming, spacecraft final checks and fairing installation, tower removal, LOX servicing, and the terminal count. The T-1 countdown extends over about eight hours; the T-0 countdown extends from 14 to 15 hours, plus a one-hour built-in hold before the terminal count begins at T-35 minutes. If all goes well, the Delta vehicle can be launched within a few seconds of the opening of the scheduled launch window.

III. ANALYSIS OF DELTA LAUNCH OPERATIONS

Most of the information relating to test results, failures and repairs, which provide a basis for analysis of Delta checkout and launch operations, is derived from reports issued at three points during the checkout sequence: (1) the "Hangar Meeting Agenda" (Reference 9) which is issued following the dual-composite test (see Table 2), (2) the "Pad Meeting Agenda" which is issued following the T-3 day tests (Reference 10), and (3) the "Flash Report" which is issued eight hours after the launch (Reference 12). Other information was obtained from Delta project personnel and from reports dealing with the history of the various flights (References 11 and 13).

The "Hangar Meeting Agenda" results from a meeting between NASA and DAC personnel after completion of hangar-area testing. These reports enumerate failures and other discrepancies detected in the dual-composite tests and during preceding activities, which include the pre-composite tests and some other checks performed while the vehicle is in the hangar. These reports also indicate measures that had been taken, or that would be taken to correct the detected discrepancies and failures.

The second available data source, the "Pad Acceptance Meeting Agenda", results from a meeting between NASA and DAC personnel after completion of the acceptance tests on T-6 day. This report enumerates failures and discrepancies detected during the T-6 day tests, and during all testing activities occurring between VOS and the V-6 day tests. It also indicates remedial actions that had been, or would be, taken. The "Flash Reports" contain much of the information contained in the two meeting agenda, plus additional data relating to the launch and vehicle mission.

Both agenda reports were available for most of the Delta launches, as were most "Flash Reports". Reasonably complete data of this type have been assembled for Flights 5 through 11, Flight 13, and Flights 15 through 17. In addition partial data have been obtained for Flights 4, 12, 14, and 18 through 20. Reports on several of the early flights are classified and therefore were not included in this study.

The contents of the chapter are primarily the result of gleaning information from the types of records described above, which in some cases, had then to be interpreted in light of other knowledge acquired during this study.

1. CHECKOUT AND LAUNCH SCHEDULES

A brief history of the Delta program has been presented in Section II. 1. Table 1, referred to in that section, summarizes all of the Delta missions and launch dates to the present time.

The nominal Delta schedule has been discussed, in some detail, in Section II. 3 (see Table 2). To investigate the differences between the nominal and actual launch preparation schedule, the assembled historical information, described above, was used to develop an average schedule for the final phases of the Delta launch preparations (Figure 1).

Initially, consideration was given to the entire time spent by the vehicle at AMR. The time from arrival of the first component (usually the booster) at AMR, until launch, was found to have varied widely, from over 17 months (Delta 8) to less than three months (Delta 15), as shown in Table 3.

The average time span, for the flights considered, has been about 7.3 months; the last five flights for which data are available, however, have averaged about 4.7 months. These relatively long time-spans, in general, do not seem to be the result of any difficulty in meeting preparation schedules, but appear to have been caused both

Table 3
Delta Vehicle - Time at AMR

Delta No.	Initial Arrival	Arrival Date	Launch Date	Elapsed Time-Months
4	Booster	8-8-60	3-25-61	7.56
5	Booster	6-9-60	7-12-61	13.10
6	N. A.	N. A.	8-16-61	N. A.
7	2nd stage	8-11-61	2-8-62	5.92
8	Booster	9-21-60	3-7-62	17.53
9	2nd stage	6-15-61	4-26-62	10.36
10	2nd stage	2-1-61	6-19-62	4.59
11	Booster	6-27-61	7-10-62	12.43
12	Booster	1-31-62	9-18-62	7.59
13	Booster	5-18-62	10-2-62	4.49
14	Booster	7-23-62	10-27-62	3.10
15	Booster	10-4-62	12-13-62	2.30
16	Booster	11-1-62	2-14-63	3.43
17	Booster	10-16-62	4-2-63	5.56
18	Booster	11-20-62	5-7-63	5.56
19	N. A.	N. A.	6-19-63	N. A.
20	Booster	12-17-62	7-26-63	6.62

N. A. - Not Available.

by slippage of the payload schedules and by the success of the Delta program. The latter cause is explained by noting that if the initial launch of a spacecraft is successful, the backup spacecraft usually available is not launched, thereby eliminating a launch from the Delta schedule.

Early in this program, it was not uncommon for vehicle components to be reassigned to different missions, with attendant changes of configuration. Occasionally, reassignment occurred several times, as in the case of Delta 5 where the booster (1st stage) was prepared for five missions, and the second stage for three. As the program progressed, however, these changes became the exception, rather than the rule.

Because the total time-span at AMR did not appear to be of primary significance, a detailed investigation was made of the period starting with the pre-composite test, which occurs at T-35 to T-27 days, and ending at launch.

The number of days required to complete each of seven phases of the preparation schedule, in terms of actual days worked, and of calendar days, were compiled in Table 4. These segments were averaged for those flights for which complete data were available (Delta 6

Table 4
Actual Delta Vehicle Time Spans

Assumed Start of Pre-Composite Test Through Launch
Days Worked & Calendar Days Used... Item Complete To Item Complete

Delta No.	TIME SPAN ~ DAYS																NOTE
	Start Pre-Comp. to Launch		Pre-Comp.		Pre-Comp. to Dual Comp.		Dual Comp. to VOS (II)		VOS (II) to T-6		T-6 to T-3		T-3 to T-1		T-1 to Launch		
	Days Worked	Cal. Days	Days Worked	Cal. Days	Days Worked	Cal. Days	Days Worked	Cal. Days	Days Worked	Cal. Days	Days Worked	Cal. Days	Days Worked	Cal Days	Days Worked	Cal. Days	
5	43	63	1	1	-	-	-	-	-	-	3	6	3	4	1	1	
6	36	49	1	1	1	1	14	21	12	18	4	4	3	3	1	1	
7	72	105	8	12	6	8	41	62	11	15	1	1	2	4	3	3	
8	24	43	3	3	1	3	1	10	9	13	6	8	2	4	2	2	
9	42	58	6	8	3	5	5	7	11	15	2	2	2	4	13	17	(1)
10	33	48	2	2	1	3	17	24	7	11	4	4	1	3	1	1	
11	39	56	15	22	2	2	6	10	10	14	3	4	2	3	1	1	
12	25	35	4	6	5	7	2	2	7	12	3	3	3	4	1	1	
13	20	23	2	2	2	2	2	2	8	11	3	3	2	2	1	1	
14	25	31	1	1	1	1	7	11	10	12	2	2	2	2	2	2	
15	25	35	4	6	5	7	3	5	7	9	3	5	2	2	1	1	
16	27	36	1	1	2	2	2	4	14	20	5	6	2	2	1	1	(2)
17	62	106	18	44	4	6	7	9	26	36	1	3	5	7	1	1	
18	23	33	4	6	4	6	3	3	6	10	3	3	2	4	1	1	
19	-	-	-	-	-	-	-	-	8	13	3	3	2	4	2	2	
20	32	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Total	453	658	69	115	37	53	110	170	136	196	40	48	30	44	29	33	(3)
Average	34.8	50.6	5.3	8.8	2.8	4.1	8.5	13.1	10.6	15.1	3.1	3.7	2.3	3.4	2.2	2.5	

(1) Second stage changed after helium leak found on first launch attempt.

(2) F-3 not actually complete until F-1 complete due to over-lap.

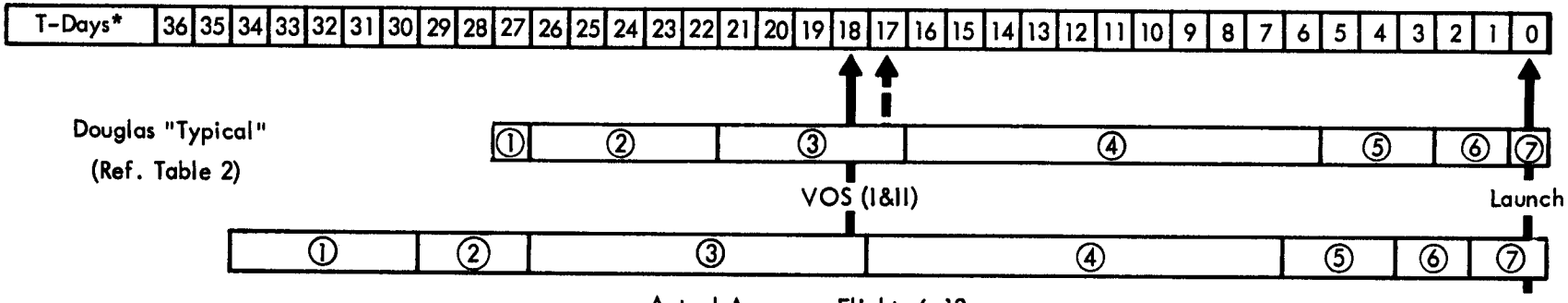
(3) Total and average for only those flights for which complete data are available, Flights 6-18.

through 18), and the results were used to construct the average preparation schedule. Figure 1 shows the average workday schedule which resulted, together with a predicted "typical" schedule supplied by Douglas.

The "typical" schedule used by Douglas in various publications (e.g., Reference 1) has been adopted as a basis for comparison in the absence of the original launch schedules for each flight. It appears, however, that this typical schedule is reasonably representative of the planned schedule for the flights considered.

Although the Delta preparation schedule is purposely loose, designed to accommodate delays, the average launch required seven days more than the 28 days allowed by the nominal schedule from the start of the pre-composite test, through launch (Figure 2). In the average schedule, Figure 1, only one day of slippage occurs after VOS (vehicle-on-stand). It occurs between F-1 and launch. Prior to VOS, three days of slippage occur between the dual composite test and VOS, and four days occur during the pre-composite phase. The period between completion of the pre-composite and the dual composite tests, however, is accomplished in one day less than that allotted by the nominal schedule.

FIGURE 1
Comparison of "Typical" Delta Vehicle Launch Schedule
To Average Experienced
Start of Pre-Composite Test Through Launch



Schedule Phases:

① Start Through Completion of Pre-Composite Test

② End Pre-Composite Through Completion of Dual Composite Test

③ End Dual Composite Through Second Stage VOS (Vehicle-On-Stand)

④ VOS Through Completion of T-6 Day Acceptance Test

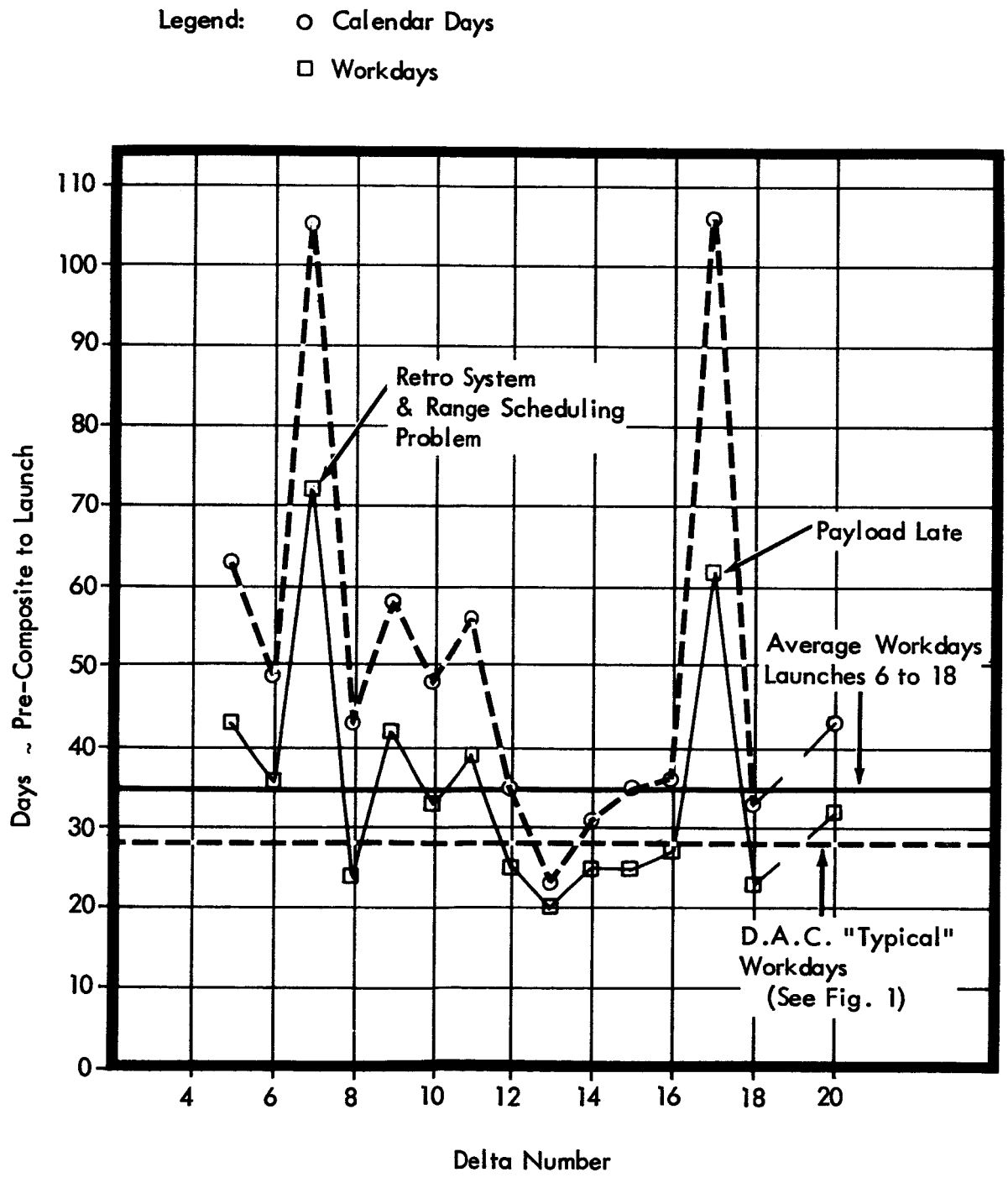
⑤ End T-6 Day Test Through Completion of T-3 All-Systems Test

⑥ End T-3 Day Test Through T-1 Day Countdown

⑦ End T-1 Day Countdown Through Launch

*Workdays

FIGURE 2
Delta Vehicle ~Time to Launch
(From Start of Pre-Composite Test)



Considering further the period between the completion of dual composite and VOS, if Delta 7 were excluded from the average, the average days expended during this particular period would virtually agree with the DAC typical schedule. The very long period of 41 work-days on Delta 7 appears to have been caused by a combination of several technical problems, which could have been rectified in a reasonably short period, forcing a range scheduling "log jam" due to the forth-coming Christmas holiday. Therefore, the first stage of Delta 7 was stored for two months and appears to have been worked on for only part of this time.

Further study of Figure 2 indicates that the days elapsed between the start of pre-composite and launch diminishes with increasing experience (i.e., with increasing launch number). This trend is especially evident if Launches 7 and 17 are ignored. Among the last eight flights, for example (Flight 19 is excluded, as data was not available) only one flight has required more than the average number of workdays (Delta 17; payload late), and only two have required more than the 28 days allotted by the DAC schedule. These eight vehicles averaged 29.9 days, from start of pre-composite through launch, including the exceptionally long stay on the launch pad of Delta 17. Using the most recent flights as indication, it appears the Douglas "typical launch schedule" is realistic for use in planning future launches.

Table 5 outlines the extent of, and the reasons for, delays which caused scheduled launches to be missed by a day or more, on nine of the sixteen flights considered. These delays were, for the most part, "last-minute items" (i.e., occurred within the final days of preparation). Since delays encountered early in the checkout may have resulted in the scheduled launch date being changed, Table 5 may not represent all missed launches. Counting the flights with known missed launches, and all others requiring in excess of 28 days between start of pre-composite and launch (see Figure 2), it may be concluded that 12 of the 16 launches, or 75 per cent, missed the initially scheduled launch date for one reason or another.

It is interesting to note that three of the flights on which launches were definitely missed (Delta 8, 14, and 16) are among the seven which required less than the nominal 28 days from pre-composite through launch. Flight 8 is particularly interesting. Although this vehicle spent more total time at AMR than any other, it required only 24 workdays for completion of preparation, from the start of the pre-composite test through launch, including six days of unscheduled delays (but excluding a period of inactive storage).

It is quite evident that maintenance of a rigid launch schedule has not been essential to the Delta program. The launch windows for the

Table 5
Missed Launches - Delta Vehicle

(Scheduled Launch Missed by One or More Days)

Delta No.	Launch Delay, Workdays	Day Delay Encountered	Cause of Failure to Launch
5	1	T-1	A combination of unsatisfactory first stage yaw gyro drift characteristics, and a ground station antenna problem at Wallops Island.
7	36	T-23	Second stage retro system parts shortage caused range scheduling problem, necessitating rescheduling launch.
	1	T-0	At T-9 min. a pressure regulator had to be adjusted; this combined with a faulty work platform caused the window to be missed.
	1	T-0 (2nd)	A bad blockhouse instrumentation amplifier made a good system appear faulty ... missed the window.
8	5	T-3	Launch postponed for seven days after successful F-3 days ... reason not clear.
	1	T-0	Drop in LOX pressure ... no start at T-O.
9	12	T-0	Helium leaks found at T-6 min. Second stage changed.
14	1	T-0	Postponed launch to allow time for additional investigation of booster rate gyro problem noted on Flight 13. (Launches 13 and 14 were relatively close together.)
16	1	T-1	Combination of replacement of first stage gyro with occurrence of an electrical storm.
17	17	T-9	Payload late.
	3	T-1	Payload problems.
19	1	T-0	Separation band bolt failed while being torqued.
20	1	T-3	Problem with second stage thrust actuator potentiometers.
	1	T-0	Payload problem.
	1	T-0 (2nd)	First stage gyro drift excessive.

spacecraft involved occur frequently, and the program management has not allowed unnecessary haste to jeopardize accomplishment of the launch mission.

2. UNSCHEDULED ACTIVITIES ANALYSIS

One way of evaluating the quality of the assembled vehicle, and the excellence of the checkout procedure and execution, is to study the "unscheduled activities" encountered during the previous Delta launches. For example, problems which repeat from vehicle to vehicle, or a large occurrence of problems on one stage or on one vehicle, would indicate the need for appropriate improvements and changes. The lack of trends or correlations of unscheduled activities with launch number, the time the vehicle spends at AMR, or other factors, can be just as important as the occurrence of trends. In any case, the study of unscheduled activities is an attempt to learn from experience.

The term "unscheduled activities", as used in this investigation, includes all non-standard operations reported during preparation of the Delta vehicle and payload for launch. Included are such items as special modifications, investigation of problems (real and suspected), the detection and correction of faults and failures, adjustments in the

launch vehicle and payload, and correction of problems in the ground support and test equipment.

The detection and correction of faults and failures have been further classified in order to isolate "critical faults". This type of unscheduled activity is the detection and correction of faults which, if uncorrected, would likely have:

(a) directly jeopardized the spacecraft mission, or

(b) reduced the reliability of the launch vehicle, data, or payload systems.

The placement of items in this category was, therefore, limited to serious faults in flight systems, ground equipment items being excluded. In addition, the only items placed in this category were faults discovered by the checkout procedure, not caused by it, as happened in some cases; i. e., faults caused by human errors in carrying-out tests were omitted.

(1) Method of Analysis

The unscheduled activities have been sorted and classified to determine:

(a) their relation to the amount of time required to prepare and launch the vehicle,
(b) the phase of the preparation schedule in which they occurred,

(c) the probable cause,
(d) the number of faults originating at the factory,
(e) the related vehicle stage, and
(f) the related system.

It must be recognized that classification of unscheduled activities was a function of the judgment of the persons performing this study, and because of the brevity of launch records, it was often not possible to feel confident that each item was placed in the correct category. However, since a large quantity of data was available for analysis, it is likely that the relative levels of occurrence of given types of activities are correct, although absolute numbers of occurrences may be in error.

One short-coming of the analysis presented is that it does not show the time or cost associated with the various unscheduled activities. Thus, an item that necessitated a one-hour delay and cost several dollars to correct, is effectively weighted the same as an item that may have held up a launch for several days and cost far more. Although it is highly desirable to place a relative cost on the delays, the data and information required to do this were not available. Another limitation resulted from the elimination of flights for which the unscheduled activities records were obviously incomplete. These flights were 1 through 4, 12, 14,

and 18 through 20. Therefore, in most cases, only eleven of twenty flights, or 55 per cent of the total were considered.

A summary of the tables and figures included is as follows:

Table 6 - Gives the average distribution, by launch preparation phase, of all unscheduled activities and critical faults for Delta Flights 5 through 11, 13, and 15 through 17. The data were incomplete for the other flights. This table was derived from Table 7.

Table 7 - Shows the distribution of all unscheduled activities and critical faults over the work phases for the same individual launches as averaged in Table 6.

Table 8 - Classifies the unscheduled activities by probable cause, for individual flights. The seven categories selected were as follows:

1. Development and Learning Problems: - Items of unsatisfactory design or procedure discovered and corrected at AMR, plus human errors made during the performance of integration and checkout procedures at AMR. Such problems with flight systems, ground support, and test equipment were included in this category.

2. Unscheduled Modifications: - Modifications required by changes in the assigned mission, and factory-ordered improvements accomplished at AMR.

3. Malfunctions and Sub-Standard Quality: - Problems of this nature with flight, ground support, and test equipment were included in this category.

4. Questionable Items Finally Classed As Acceptable: - Special inspections and tests required to investigate suspected problems, as well as items of marginal quality were placed in this group.

Table 6
Delta Vehicle

Average Occurrence of Unscheduled Activities and Critical Faults Per Test Phase

Flights 5 - 17 (Delta 12 and 14 excluded)

Phase of Preparation Schedule	Unscheduled Activities		Critical Faults	
	Average No. /Vehicle	Percent of Total	Average No. /Vehicle	Percent of Total
Before pre-composite test	19.6	36.4	7.4	31.1
During pre-composite test	3.5	6.6	2.0	8.4
End pre-composite thru VOS 2nd stage	3.8	7.1	1.9	8.0
End VOS thru T-6 tests	18.0	33.4	8.8	36.8
End T-6 tests thru T-3 tests	3.4	6.2	1.5	6.1
End T-3 tests thru T-1 countdown	3.0	5.6	1.5	6.1
End T-1 thru launch	2.5	4.7	0.8	3.4

Table 7
Delta Vehicle

Distribution of Unscheduled Activities and Critical Faults
By Test Phase for Individual Launches

Delta No.	Before Starting Pre-Composite Test		During Pre-Composite Test		End Pre-Composite Thru VOS 2nd Stage		End VOS Thru T-6 Test		End T-6 Tests Thru T-3 Tests		End T-3 Thru T-1 Count-Down		End T-1 Thru Launch		Totals	
	All	Crit.	All	Crit.	All	Crit.	All	Crit.	All	Crit.	All	Crit.	All	Crit.	All	Crit.
5	28	4	2	0	3	3	11	5	4	2	8	3	4	2	60	19
6	15	0	1	2	4	1	23	9	6	1	6	2	1	0	56	15
7	15	7	1	0	5	2	6	5	0	0	3	0	3	1	33	15
8	19	7	0	0	3	1	20	16	1	1	1	1	1	1	45	27
9	24	7	2	2	6	4	20	8	2	0	3	1	3	1	60	23
10	21	10	0	0	0	0	22	7	2	3	2	1	2	0	49	21
11	21	6	1	0	0	0	8	3	5	2	2	1	4	1	41	13
12							Incomplete Data									
13	28	24	6	2	2	2	21	10	5	0	4	5	3	1	69	44
14							Incomplete Data									
15	25	12	6	4	11	5	17	4	7	4	0	0	3	0	69	29
16	9	2	3	2	1	0	17	11	4	3	1	1	4	2	39	21
17	10	3	17	10	7	3	33	19	1	0	3	1	0	0	71	36
Total	215	82	39	22	42	21	198	97	37	16	33	16	28	9	592	263
Avg.	19.6	7.4	3.5	2.0	3.8	1.9	18.0	8.8	3.4	1.5	3.0	1.5	2.5	0.8	53.8	23.9
%	36.4	31.1	6.6	8.4	7.1	8.0	33.4	36.8	6.2	6.1	5.6	6.1	4.7	3.4	100	100

Table 8
Delta Vehicle

Distribution of Unscheduled Activities by Probable Cause

Delta No.	Cause Category Number*							Total	Remarks
	1	2	3	4	5	6	7		
5	13	9	21	13	0	1	3	60	
6	3	15	23	10	1	3	1	56	
7	5	5	16	5	1	0	1	32	
8	2	10	29	2	0	0	2	45	Long stay at AMR
9	7	9	32	2	1	2	7	60	2nd stage changed
10	4	2	37	2	0	2	2	49	
11	4	1	27	5	0	0	4	41	
12	1	2	26	2	0	0	6	37	Incomplete data
13	8	7	48	4	0	1	1	69	
14	2	7	32	2	0	1	1	45	Incomplete data
15	8	15	36	7	0	2	1	69	
16	3	5	31	0	0	0	0	39	
17	3	4	49	5	3	1	6	71	Spacecraft late

* Categories:
1. Development and learning problems: unsatisfactory design or procedure (change made at AMR); human errors during performance of integration and check-out. Ground support and test equipment included.
2. Unscheduled modifications.
3. Malfunction and sub-standard quality. Ground support and test equipment included.
4. Questionable items finally classed as acceptable.
5. Scheduling problems (range, vehicle or payload).
6. Engineering tests and investigations not required for check-out.
7. Parts shortages.

5. Scheduling Problems: - This category was intended to include problems with range scheduling, conflicting vehicle tests, and the late arrival of vehicle stages or the payload.

6. Engineering Tests and Investigations: - Work not required for preparation of the vehicle for launch, but rather for evaluation of some special characteristics for engineering purposes.

7. Parts Shortages: - Problems caused by unavailable parts, including the removal of parts from one vehicle for use on another.

Table 9 - Shows the number of defects and critical faults which apparently originated "at the factory" (vendors as well as prime contractors included), for individual flights. In some cases, the nature of a fault, or recorded remarks of AMR personnel, clearly indicated that a fault was, or was not, a factory item. In the majority of cases, however, such evidence was not available, and faults were counted as factory items if they could, in the opinion of the classifier, reasonably be assumed to have originated there. Table 9 shows the number of factory items, the total number of defects, the number of factory items that were also critical faults, the total critical faults, and the division of factory items between the stages. Gyroscope problems were not classed as factory items, since higher than design performance is expected from them on Delta (see p. 60).

Table 10 - Indicates the distribution of unscheduled activities among the three vehicle stages and the payload, for individual flights. It should be noted that the unscheduled activities related to the payload are only those which occurred after the spacecraft reached the launch pad.

Table 11 - Compares the number of critical faults found in the first stage with those found in the second stage.

Table 9
Delta Vehicle

Malfunctions and Sub-Standard Items
Believed to have Originated at the Factory

Delta No.	Total Items In Category Three[1]	Factory Origin Items In Category Three	Total Critical Faults	Factory Origin Critical Faults	"Factory" Items Distribution by Stage[2]	
					Stage I	Stage II
5	21	11	19	11	7	4
6	23	15	15	12	6	9
7	16	14	15	13	8	6
8	29	20	27	19	10	10
9	32	22	23	17	8[3]	14[3]
10	37	27	21	19	16	11
11	27	16	13	9	7	9
12			Incomplete Data			
13	48	36	44	34	31[4]	5[4]
14			Incomplete Data			
15	36	23	29	21	9	14
16	31	11	21	10	5	5
17	49	27	36	24	7	20
Total	349	211	263	189	75	88
Avg.	31.7	19.2	23.9	17.2	8.3	9.8

(1) Category 3, Table 8

(2) No "Factory" Items were found for the third stage (note that one item on Flt. 16 could not be identified with a stage, and was classed as miscellaneous.)

(3) Not included in average; two 2nd stages for this flight.

(4) Not included in average; first of Block II boosters.

Table 10
Delta Vehicle

Distribution of Unscheduled Activities by Vehicle Stage

Delta No.	Stage I	Stage II	Stage III	Payload	Misc.*	Total	Remarks
4	16	26	0	0	10	52	Incomplete data
5	25	25	1	0	9	60	
6	21	25	0	2	8	56	
7	12	14	0	1	6	33	
8	20	23	0	0	2	45	
9	13	43	0	1	3	60	Two second stages
10	21	23	1	1	3	49	
11	15	21	1	2	2	41	
12	21	10	0	2	4	37	Incomplete data
13	48	13	3	0	5	69	First of Block II boosters
14	26	16	1	0	2	45	Incomplete data
15	21	39	1	0	8	69	
16	21	11	0	0	7	39	
17	29	34	0	4	4	71	
Totals	309	323	8	13	73	726	All flights
	246	271	7	11	57	592	Flights with complete data
	185	215	4	10	49	463	Flights with complete data less Flights 9 and 13

* Primarily ground support and test equipment; a few interstage items are included.

Table 11
Delta Vehicle Distribution of Critical Faults

Stage I vs. Stage II

Delta No.	Number of Critical Faults		Remarks
	Stage I	Stage II	
4	8	7	Incomplete data
5	9	9	
6	6	8	
7	8	7	
8	13	14	
9	8	15	Two second stages
10	14	7	
11	6	7	
12	12	7	Incomplete data
13	36	8	First Block II Booster
14	17	9	Incomplete data
15	12	17	
16	14	6	
17	17	17	
Totals	143	115	Flight with complete data
	180	138	All flights
	99	92	Total for flights with complete data less Flights 9 and 13

Table 12 - Shows the distribution of unscheduled activities and of critical faults, among the various subsystems involved.

The following figures were plotted from the data presented in the tables described above.

Figure 3 - Is a plot of the total number of unscheduled activities, together with the number of critical faults, for each flight, versus the total time elapsed between arrival of the booster at AMR and launch.

Figure 4 - Is similar to Figure 3, except that the time represented is the period from the start of the pre-composite test to launch, and the unscheduled activities and critical faults are those which occurred during this period, on all stages.

Figure 5 - Shows the total number of unscheduled activities, together with the total number of critical faults, recorded for each of the Delta flights for which complete data are available.

Figure 6 - Illustrates the distribution of unscheduled activities among the seven "cause categories" of Table 8. Again, only those flights for which complete data are available have been used.

Figure 7 - Shows the total number of unscheduled activities believed to have originated at the factory for each of the Delta flights for which complete data are available.

(2) Discussion of Results

Although the launching of twenty Delta vehicles (eleven are analyzed in detail) does not represent a large number of samples in a statistical sense, some revealing trends and correlations are apparent in the checkout and launch records

Table 12
Delta Vehicle
Distribution of Unscheduled Activities and Critical Faults by Systems

Delta Number	Control and Guidance		Destruct		Engine		Electrical Electronics*		Fuel and Oxidizer		Ground Support, Control, etc.		Hydraulic		Instrumentation and T/M		Mechanical		Pneumatic or Gas		Separation Systems		Miscellaneous		Totals	
	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit	All	Crit
5	14	5	0	0	1	0	8	4	6	2	9	0	7	4	5	2	1	1	1	1	1	0	7	0	60	19
6	12	4	1	1	0	0	12	6	2	1	7	0	4	1	10	2	4	0	2	0	1	0	2	0	56	15
7	9	5	0	0	0	0	8	5	1	1	5	0	1	1	4	2	1	0	3	1	0	0	1	0	33	15
8	15	11	0	0	2	0	9	5	8	8	2	0	0	0	4	2	2	1	0	0	0	0	3	0	45	27
9	19	7	1	1	0	0	26	11	1	1	1	0	2	0	4	1	0	0	3	2	0	0	3	0	60	23
10	11	5	0	0	2	1	16	7	5	1	3	0	3	2	7	4	1	1	1	0	0	0	0	0	49	21
11	7	3	0	0	3	0	15	6	3	0	1	0	6	3	2	1	3	0	0	0	0	0	1	0	41	13
12	Incomplete Data																									
13	14	11	4	3	0	0	5	3	4	3	5	0	5	3	27	20	3	1	0	0	1	0	1	0	69	44
14	Incomplete Data																									
15	12	8	3	2	1	0	15	8	2	0	6	0	1	1	18	7	10	2	1	1	0	0	0	0	69	29
16	17	9	1	1	0	0	9	5	2	2	4	0	1	1	4	3	0	0	0	0	0	0	1	0	39	21
17	8	4	1	0	1	0	22	11	5	3	1	0	3	3	23	14	1	0	2	1	0	0	4	0	69	36
Total	138	72	11	8	10	1	144	71	39	22	44	0	33	19	108	58	26	6	13	6	3	0	23	0	592	263
Avg.	12.5	6.6	1.0	0.7	0.9	0.1	13.1	6.5	3.5	2.0	4.0	0	3.0	1.7	9.8	5.3	2.4	.6	1.2	.6	0.3	0	2.1	0	53.8	23.9
%	23.3	27.4	1.9	3.0	1.7	0.4	24.3	27.0	6.6	8.4	7.4	0	5.6	7.2	18.2	22.1	4.4	2.3	2.2	2.3	0.5	0	3.9	0	100	100

* This category was used for electrical items which could not knowledgeably be placed in some other category, e.g., controls and guidance or instrumentation and telemetry.

FIGURE 3
Number of Unscheduled Activities and Critical Faults
vs.
Total Booster Stay at A.M.R.
Delta Flights 5-17 (6, 12, & 14 Excluded)

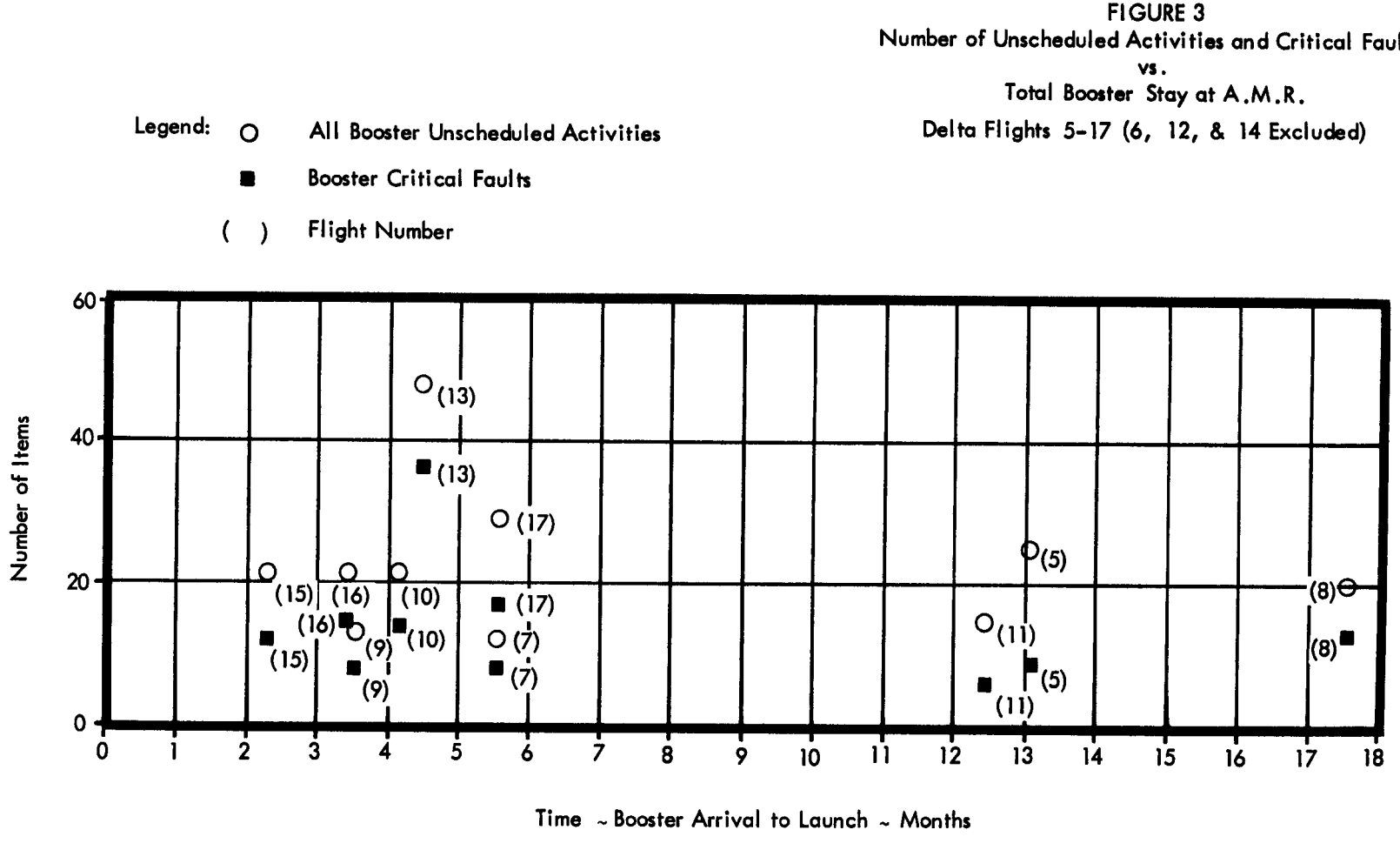


FIGURE 4
Delta Vehicle
Unscheduled Activities & Critical Faults
for Period from Start of Pre-Composite Test
to Launch vs. Time Required
Flights 5-17 (12 & 14 Excluded)

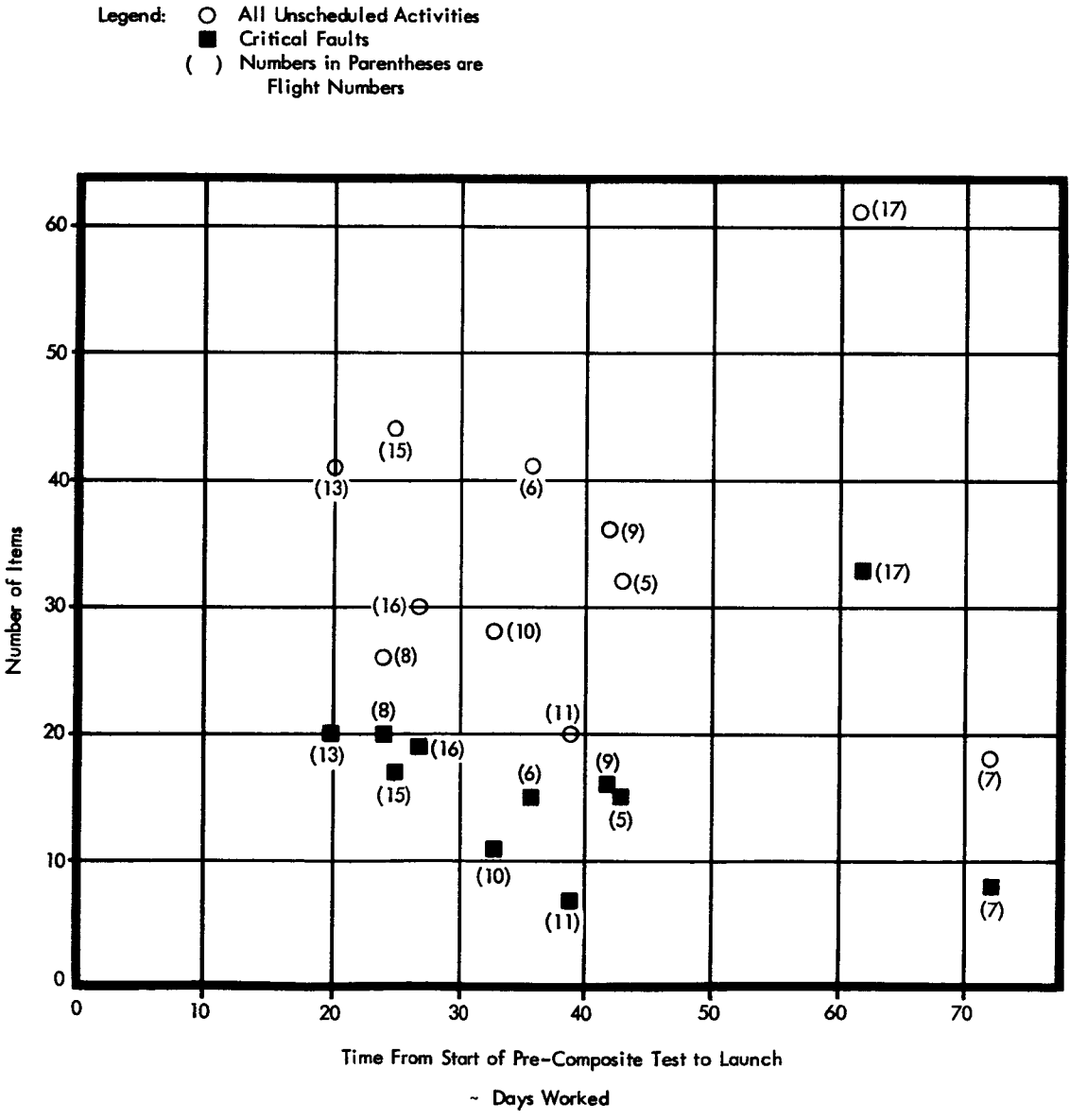


FIGURE 5
Delta Vehicle
Unscheduled Activities and Critical Faults
vs. Flight Number

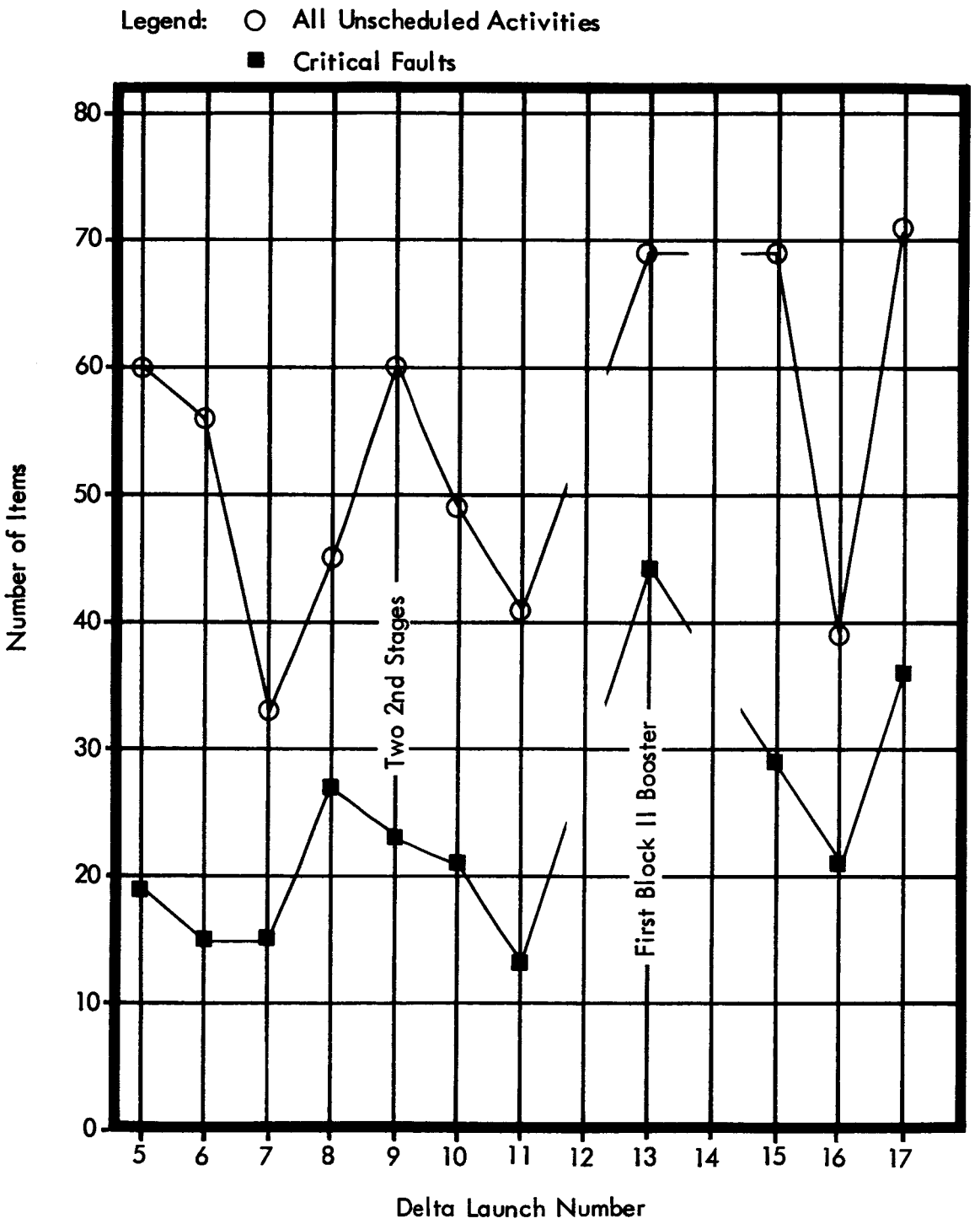


FIGURE 6
Delta Vehicle
Unscheduled Activities vs. Flight Number
Classified According to Probable Cause

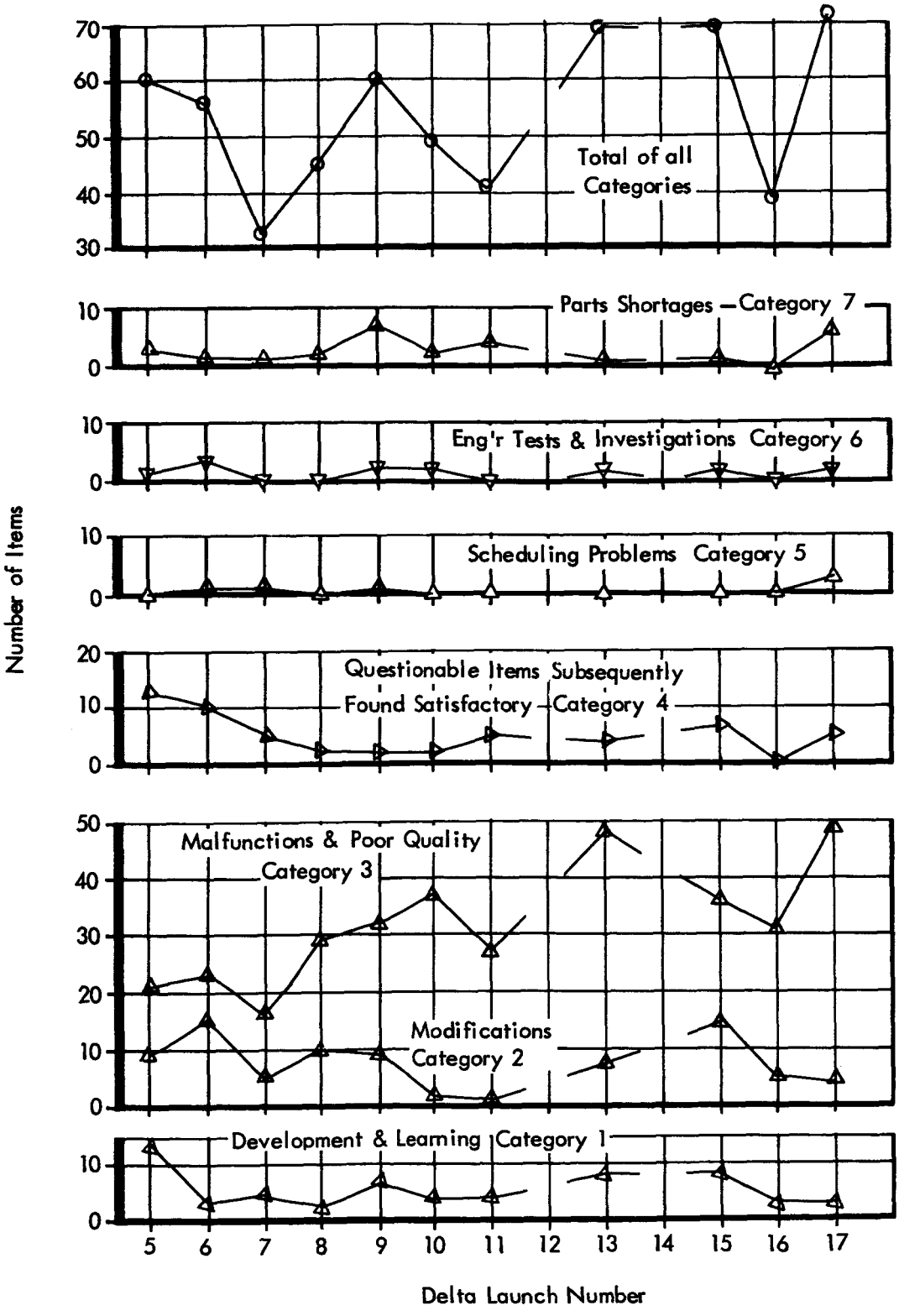
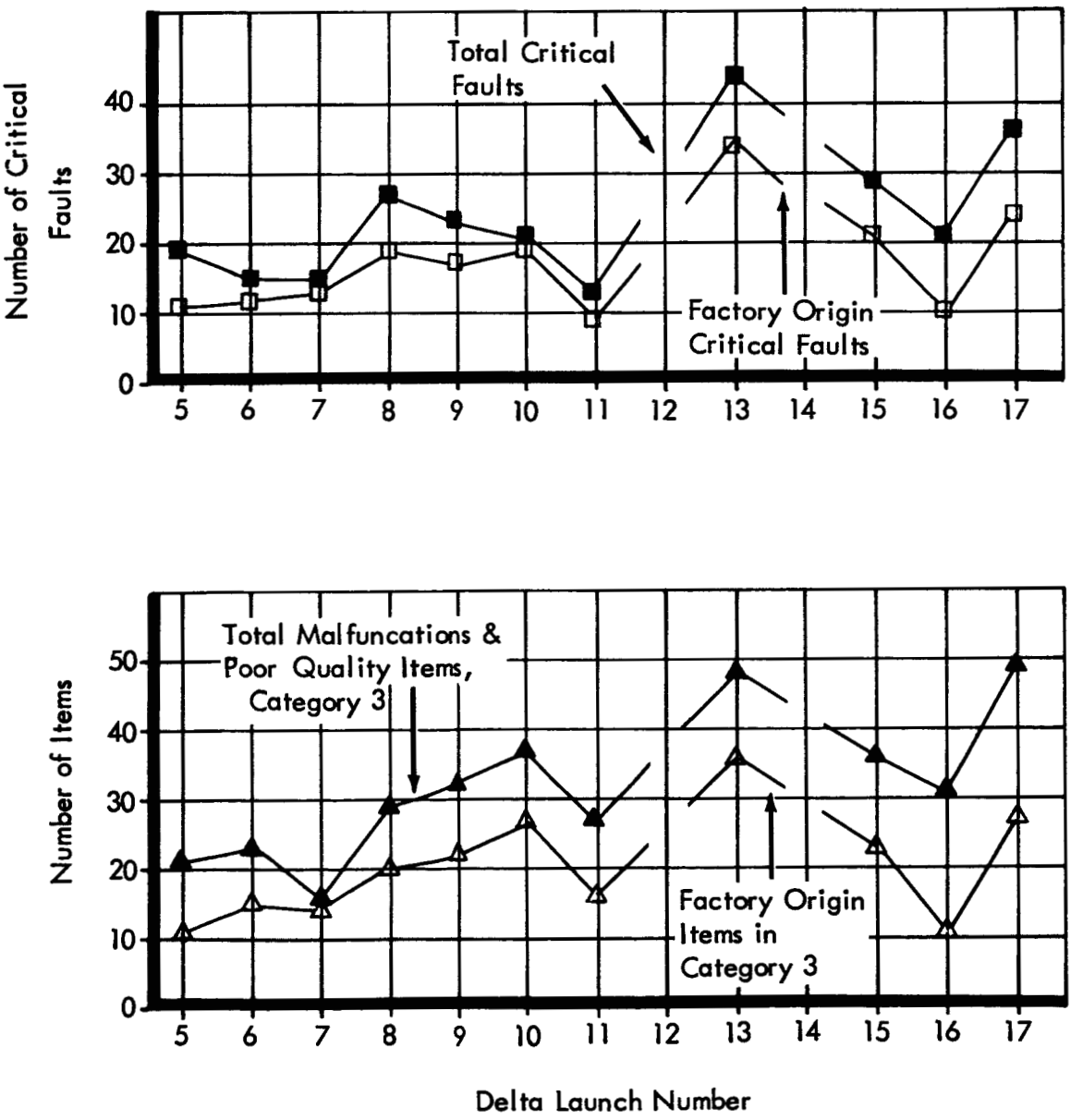


FIGURE 7
Delta Vehicle
Malfunctions & Sub-Standard Items Believed to Have
Originated at the Factory



of these flights. In addition, several informative conclusions can be drawn from individual occurrences which are not dependent on any sort of averages.

Figure 3, which presents the total number of unscheduled activities which occurred on the booster, versus the total time the stage spent at AMR, reveals that long storage times do not necessarily result in additional problems during checkout. In fact, Delta 8, whose first stage (see Table 3) spent the longest period of time at AMR (17.5 months), incurred virtually the same number of total unscheduled activities and critical faults as the first stage of Delta 15, which spent the shortest time at AMR (2.3 months). The first stage of Delta 13, which spent 4.5 months at AMR had the greatest number of critical faults and unscheduled activities of any stage plotted in Figure 3. By way of explanation, however, the first stage of Delta 13 was the first stage delivered in Block II of the Delta booster series (see Tables 10 and 11). One qualifying note concerning Delta 8 must be mentioned; the first stage was serviced at several times during its storage time due to some items exceeding their "shelf life". In addition, engineering modifications were made as ordered by the factory and some parts were removed (and later replaced),

apparently as the need arose on other vehicles undergoing checkout. These items were not counted as unscheduled activities since they did not occur during the period the vehicle was actively being prepared for launch, nor did they result from normal checkout and launch procedures. For these reasons the comments made above are still considered valid.

The total number of unscheduled activities incurred on a vehicle does not clearly correlate with the time required to complete the checkout between pre-composite and launch. Delta 13 was checked-out, from pre-composite to launch, in less time than any other vehicle, in spite of having more than the average total number of unscheduled activities and critical faults. Delta 17 which required the second longest period from pre-composite to launch, had the greatest number of unscheduled activities and critical faults, which seems understandable. Delta 7 had the least of these, however, and yet took the longest time to checkout, simply because of a scheduling problem and the intervening Christmas holidays (see Section III.1, p. 31). Summarizing Figures 3 and 4 it appears that there is no correlation between unscheduled activities or critical faults and total vehicle time at AMR, and there is only slight correlation of checkout time

between pre-composite and launch with the number of activities and faults that are encountered.

Table 6 shows that roughly one-third of all unscheduled activities and critical faults are discovered prior to the hangar pre-composite test. Since the period prior to pre-composite is quite long (scheduled for 37 days, Table 2) compared to the period following pre-composite (scheduled for 28 days), and since several major checks are done during this period, it seems logical that a large percentage of the problems should be discovered within this period. It is not known how many of the items discovered in this first checkout phase should be attributed to damage caused in transportation. For that matter, it is not known how many of the items discovered later are caused by transporting the vehicle to AMR. Unfortunately, no adequate means was found, during the study, for identifying those problems caused by transportation.

Table 6 also shows that approximately one-third of the total unscheduled activities and critical faults occur between VOS and T-6 days. Since component tests and many electrical tests are performed during this period, it is again logical that many problems should be found. Since only 16 per cent of all unscheduled

activities and roughly the same percentage of critical faults are encountered between T-6 and launch, it appears that the checkout procedures are accomplishing their purpose. On the average, only one critical fault per vehicle (less than four per cent of the total) is found between T-1 day and launch, again indicating a very good job of checkout is being done prior to this period.

Table 7 shows the distribution over the individual launches of those items averaged and presented in Table 6. In most columns it is apparent that the averages are made up of numbers which do not widely differ from the average.

It is apparent from both Table 7 and Figure 5 that there is no trend of decreasing critical faults and total unscheduled activities with increasing experience. In fact, the trend could conceivably be considered to be the opposite. Considering the accuracy of the data it is believed most correct to conclude that there is no meaningful trend detectable. (Delta 13 has previously been identified as being the first to use a Block II booster, which evidently accounts for it having so many critical faults.) One difficulty in evaluating trends or explaining the occurrence of unscheduled activities lies in the reports that were used to make the analysis. It is possible that the increasing experience gained

by the test and checkout crews might either result in improved reporting of problems, or result in improved detection of previously overlooked problems.

Table 8 and Figure 6 show the distribution, by probable cause, of all unscheduled activities over the individual Delta launches. They show that the largest percentage of unscheduled activities, approximately 60 per cent, are of type category three; i.e., malfunctions and sub-standard items. This category includes all such items for flight, ground support and test equipment. A further breakdown shows that 94 per cent of the items in category three involved flight equipment. Thus, the majority of the unscheduled activities encountered during the vehicle checkout are, in fact, precisely what the checkout procedures were designed to find. This means that the sum of all other items such as schedule problems, modifications, human errors, parts shortages, engineering tests and questionable items is approximately 40 per cent. The higher the ratio of category three to the other categories, the better the checkout task is ostensibly being accomplished. This ratio has increased somewhat toward the later Delta flights. However, at the same time, the number of items in category three has increased (see

Figure 6) while the total number of unscheduled activities and critical faults show little or no trend. It would be helpful to study the records of Flights 18, 19, and 20 prior to drawing the conclusion inferred by the above results; viz., the factory is doing a lower quality job of vehicle assembly and checkout, but the increased efficiency of the launch and checkout crew is compensating for it. At this point a final conclusion to that effect cannot be drawn.

Scheduling difficulties have occurred surprisingly few times during the attempted launch of the Delta vehicles (Table 8 and Figure 6). However, schedule changes which occurred early in the checkout procedure may not have been recorded, as such, in the launch records. Since the payload does not directly enter into the launch vehicle checkout procedure until T-10 day, it is quite likely that payload schedule slips could occur earlier, resulting in launch schedule changes that are not recorded herein. Reasons for the six scheduling problems noted were:

(a) Two cases of conflicting vehicle tests (Flights 6 and 17).
(b) Two launch slips due to a late payload on Delta 17. The first of these slips was made on the original T-9 day.
(c) One modification of the T-1 day tests because of a crowded range schedule (Delta 9).

(d) One case of a long delay prior to erecting the vehicle (Delta 7) apparently due, in part, to a crowded range schedule and the Christmas holiday (see p. 31).

As discussed previously, a system was devised for deciding what unscheduled activities and critical faults originated at the factory. The results of this approach are shown in Figure 7 and Table 9. These show that approximately 60 per cent of all defects, and 72 per cent of all critical faults were of types that could reasonably be attributed to poor workmanship, inadequate inspection, or engineering error at either a prime contractor's or a vendor's manufacturing facility. These facts suggest that, although special efforts are made to deliver highly reliable systems and components to AMR, these efforts fall short of obtaining the desired perfection. Not counting the guidance system gyro problems, which would have been assigned to the first stage if counted (see below), the first and second stages were roughly equally responsible for the "factory-caused" unscheduled activities.

The major portion of the unscheduled activities were incurred on the booster and the second stage, as shown in Table 10. Very few difficulties have been attributed to the less complex third stage or to the payload, which enters the preparation schedule just prior to the T-3 day tests. (Payload problems prior to this

time have not been considered.) A few of the payload-originated problems were schedule slippages which had very significant effects upon the launch schedule. Table 10 indicates a tendency for the second stage to generate more total unscheduled activities than the booster. However, Table 11 shows a tendency for the booster to be responsible for more critical faults than the second stage. Considering the approximate nature of the analysis, there seems to be no significant difference between the first and second stages as sources of problems. Since the second stage is more complicated from the standpoint of electronics and guidance equipment, which cause a majority of the problems encountered, this probably indicates that special efforts to attain high reliability in the second stage have been at least partially successful. Also, it must be noted that the second stage EHR ("extra high reliability") transistor effort appears to have been successful, as very few transistor problems were found in the analysis of unscheduled activities.

Table 12 shows that control and guidance systems and electrical and electronics systems are roughly equal leaders in responsibility for unscheduled activities and significant faults. This balance may be slightly deceptive since, whenever possible,

electrical problems were classed in accordance with the service provided (in the destruct system, for example). Without question, the first stage CEA (control electronics assembly) gyroscopes are the most common single source of trouble. These gyro difficulties appear to be the result of an attempt to obtain better than design performance from obsolete hardware and, as such, have constituted a special handicap for the Thor-Delta vehicle. Electronic and electrical-type items in Table 12, which includes control and guidance, electrical and electronics, and instrumentation and telemetering, account for 66 per cent of all unscheduled activities and 76 per cent of all critical faults.

3. REDUNDANCY IN TESTING AND CHECKOUT PROCEDURES

Observation of Delta test and checkout sequences indicates that certain portions of the launch vehicle undergo repeated tests during the over-all checkout procedure. Redundant testing is employed for a number of reasons. As an example, some of the tests are repeated because of a change in conditions that might be expected to affect the functioning of the item tested; viz., changing the vehicle from a horizontal to a vertical position, or changing the power supply from an external source to an internal source. In other instances, portions of the system undergo repeated tests under essentially similar conditions, as in the case

of first stage and second stage subsystems during the T-6 Acceptance Tests and the T-3 All System Tests.

These two test procedures, the T-6 Acceptance Test (Reference 4) and the T-3 All Systems Test (Reference 5), were examined in conjunction with the appropriate pad meeting agenda and flight flash reports (References 10, 11, and 12) to determine whether the repeated portions of these tests accomplished a useful purpose. (Consideration was restricted to the T-6 and T-3 day tests because adequate descriptions of other test procedures were not available for extending the investigation over the entire preparation period.)

The individual steps of the T-6 and the T-3 day procedures were compared item by item, and it was found that the T-3 day procedure repeated about 75 per cent of the steps in the T-6 procedure. Many, although not all, of the obvious differences resulted from the presence of the third stage and spacecraft in the T-3 day test.

Failure data resulting from T-6 tests were compared with failures revealed by the T-3 tests for nine Delta launches, to determine:

(1) Whether failures detected by the T-6 tests recurred during T-3 tests.

(2) Whether items that did not fail on T-6 failed on T-3.

Table 13 shows the various observations, relevant to test redundancy, which resulted from this comparison. Examination of Table 13 will show that on at least two occasions, failures detected during the T-6 tests recurred during the T-3 tests. Likewise, on at least four of the nine flights examined, the T-3 day tests revealed failures not disclosed by the T-6 day test. The second of these conditions, an item failing on T-3 that performed successfully on T-6, was illustrated in the case of Delta 8. For this vehicle, the T-6 and T-3 tests were each performed twice. In the second T-3 test, the yaw jet came on and stayed on. This serious fault, which could have occurred in any of the four tests, occurred only during the fourth running of essentially the same test.

This comparison, although admittedly of a cursory nature, demonstrates that the T-3 test has, on at least one occasion, provided useful, even critical, information not furnished in the T-6 tests. The comparison also shows that the T-3 day test provides a systematic means of checking repairs and corrective actions resulting from T-6 day failure information.

It is concluded from the preceding discussion that a much more detailed study is required of the redundant aspects of vehicle checkout procedures. Even though redundant tests provide the discovery of

Table 13
Delta Vehicle

Test Observations Related to Redundant Aspects of T-6 Day and T-3 Day Procedures

(Note: Arbitrarily Selected Flights Were Examined)

Delta Flight No.	Observations
5	(a) T-3 day test uncovered a fault previously discovered by the T-6 day test and supposedly corrected. (b) Faults suspected present during T-6 day test did not recur during redundant tests on T-3 day although no corrections were performed. (c) Some items corrected following T-6 day tests checked satisfactorily on T-3. (d) T-3 day tests uncovered several flaws on equipment previously tested and accepted on T-6.
6	(a) Same as (d) for Delta 5. One item, static inverter, was removed prior to T-6, lab checked, reinstalled, and passed T-6 tests. (b) Same as (c) for Delta 5.
7	T-3 day tests repeating T-6 day tests revealed no new problems.

Table 13 (continued)

Delta Flight No.	Observations
8	Note: T-6 and T-3 tests each performed twice. (a) T-6 day test uncovered a fault previously discovered by the T-10 RF test and supposedly corrected. (b) Some items corrected following first T-6 day tests checked satisfactorily on second T-6 tests. (c) Second T-6 day tests uncovered several faults on equipment previously tested and accepted in first T-6 test. (d) First T-3 day tests repeating T-6 day tests revealed no new problems. (e) Second T-3 day tests uncovered one flaw on equipment previously tested and accepted three times.
14	(a) Same as (a) for Delta 5. (b) E. O. (engineering ordered modifications) incorporated between T-6 and T-3, inferring a loss in redundancy.

Table 13 (continued)

Delta Flight No.	Observations
16	Note: T-3 day tests performed, in part, four times. (a) Successive T-3 day tests uncovered flaws on equipment previously tested and accepted. (b) Final T-3 day test uncovered a fault discovered in previous T-3 day test and supposedly corrected.
17	Same as for Delta 7.
18	T-6 day test uncovered a fault which was corrected and specially tested prior to T-3 day test.
19	(a) Corrective action for one problem, found on T-6 day, apparently resulted in another problem, found on T-3 day. (b) Same as (d) for Delta 5.

additional defects, many previous studies of the subject have shown that the advantages of discovering these defects must be balanced against the cost of the tests and the resultant shortened life of some components. It appears that one of the uses of the proposed analytical cost model could be to investigate the net advantages of redundant testing during vehicle checkout. The redundancy of factory testing versus hangar and launch site testing should also be investigated. In short, the observation that the redundant aspect of a portion of the vehicle checkout procedures has been of some specific help on Delta, should be investigated in far greater depth to determine if it is justified, if it pays for itself, and if the process should be further sophisticated.

IV. RESULTS APPLICABLE TO FUTURE STUDIES

The Delta project, because of its fairly large number of launches, relatively good documentation, and genuine success, provided an excellent starting point for the operations analysis of space vehicle integration, checkout, and launching. More importantly, the Delta study imposed the requirement to develop an approach to the study subject. Among the information acquired during this investigation which apply to the next phases of the study, were a better definition of the problem, an understanding of the information necessary to perform the study, and the preliminary development of an analytical cost model. Knowledge of the Delta procedures and equipment will undoubtedly also be utilized as a baseline, against which the procedures and results of other vehicles may be compared.

1. PROBLEM DEFINITION

Checkout begins at the factories where the individual stages are assembled. The integration process, which ideally starts with the vehicle design, overlaps with the checkout process because a stage generally cannot be completely checked without, at some point,

simulating or actually connecting it to its adjacent stage. The degree of completion of checkout at the factory, in turn, affects the launch site operations. The sum total effect of these efforts determine whether the vehicle, though well designed, will perform successfully or unsuccessfully. Therefore, the operations analysis of space vehicle integration, checkout and launching extends from stage assembly to successful injection of the payload into its assigned trajectory.

The object of the analysis is to make engineering and/or operational improvements in procedures wherever possible and appropriate, to relate the cost of the procedures to the value received, to isolate the major fixed (independent of launch rate) and variable (function of launch rate) costs, and to develop skills and tools which will be useful in planning future programs or optimizing the launch rate of current programs. An analytical cost model is to be developed which will permit determination, in advance, of the dollar impact of certain management decisions.

(1) Engineering Aspects

The operations analysis required must consist of several different attacks on the same subject material. The first step must be to acquire a thorough technical (engineering)

understanding of the vehicle, its major subsystems and operation, the checkout procedures, the reasoning behind the use of the procedures, and the equipment used to accomplish the work. Since this part of the analysis is to be far more than a mere time-and-motion study, individual checking operations must be evaluated, rated by priority, and determined if they are critical to the vehicle's success, or merely affect learning and confidence. The checkout procedures must be evaluated in a systems philosophy sense; i.e., an engineering determination should be made to see if systems parameters are investigated first, followed by subsystem checks that are run or not run, as influenced by the prior systems check.

The over-all philosophy of the checkout operation must be defined and evaluated. For example, if the philosophy is to completely check the stages at the factory, and ship a flyable stage to AMR (or PMR), the AMR operations should be investigated to see if they reflect this over-all philosophy. This requires that the internal consistency of the integration and checkout procedures be continuous. Whatever the testing philosophy, it is important to learn if experience has justified and substantiated that the philosophy is valid. Analysis of previous checkout and launch histories is

which are the expensive steps. This is a cost analysis of operations and procedures. Another, more important cost analysis required, is one which provides a description of the cost per launch of a given vehicle, and the relationships which are involved in determining a "cost optimum" launch rate. A preliminary result from the effort to develop such an analytical cost model is presented in paragraph IV. 2 below.

(3) Contractual and Management Aspects

The successful checkout and launch of a space vehicle requires the cooperation of many contractors and the employment of many people. This gives rise to the need for an approach to studying integration, checkout and launch, which involves determining if contract responsibilities are meaningfully defined, if they are understood by the parties involved, and if they are well executed. Communications between responsible parties and exchange of pertinent documentation are required so that the necessary technical tasks can be accomplished. The problem scope must therefore include learning if some of the problems encountered in flight, could have resulted from ill-defined tasks or lines of authority associated with the integration, checkout and launch procedures. Problems in communications, or in a sense,

"management" problems sometimes also account for the possible weak components or systems that may be detected in the engineering analysis.

2. ANALYTICAL COST MODEL

Reviewing the Delta program has given rise to two fundamental areas of cost/efficiency considerations. They are (1) the costs associated with the test philosophy, and (2) the costs associated with the use of facilities invested with extensive functional capabilities. These two areas are intimately interrelated and, in order to optimize the cost/efficiency of any program, a detailed analysis of this interaction must be made.

The following analysis is devoted to constructing a model through which these variables may be related. Although the Delta program was used as a source of information, the model is general and can, it is believed, be applied to any program. When sufficient data have been acquired, as described later, the model should be tested and revised as needed.

(1) The Basic Facilities

The fundamental facility involved in the launching of a payload is the launch pad and its associated support equipment such as the gantry and blockhouse.

For a launch facility with an initial cost of $I and an annual maintenance cost, $M (independent of destructive effects of launch) the total fixed annual costs are:

$$LA_f = I/n + M \qquad (1)$$

(neglecting interest on money)

where n = life in years.

Each launch introduces additional costs as a result of damage to the facilities of say, $d (average) per launch. Also, each launch requires the services of the range and miscellaneous support equipment. Calling these costs $R, the total annual facilities and range launch costs, neglecting interest and minus vehicle cost, are:

$$LA_{FR} = I/n + M + N(d + R) \qquad (2)$$

where N = number of launches per year.

In addition to the equipment costs, it is necessary to have an operating crew available to effect a launch. For programs with any degree of repetition, it is highly desirable to maintain the skills acquired as the program progresses. As such, the manpower needed must be retained, giving rise to a basic manpower yearly cost of, say, $P. Then, the annual launching costs for facilities, range, and labor are:

$$LA = I/n + M + N(d + R) + P. \quad (3)$$

The total launching costs per launch are:

$$L = I/nN + M/N + d + R + P/N. \quad (4)$$

Figure 8 graphically represents these per launch costs as a function of the number of annual launches. (Note: Curve for L is not drawn to scale.)

It is important to note that this model is based upon the concept that these costs are attributed to the launched vehicles. Thus, the more vehicles launched, the lower the per vehicle charges. If none are launched, the costs per vehicle are infinite since I, M, and P are still incurred.

FIGURE 8
Unit Launch Costs as a Function of Launching Rate
(Assuming Basic Crew and Facilities are Adequate
for the Maximum Launching Rate)

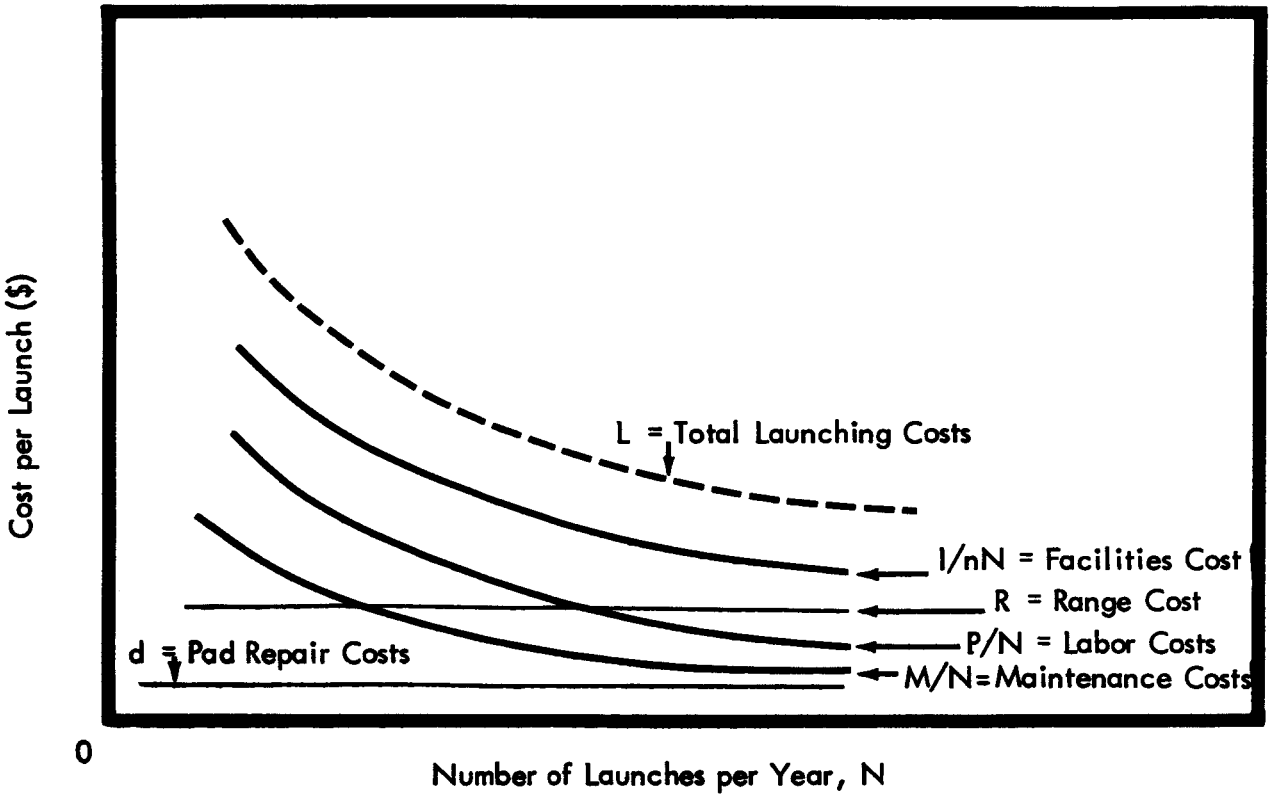
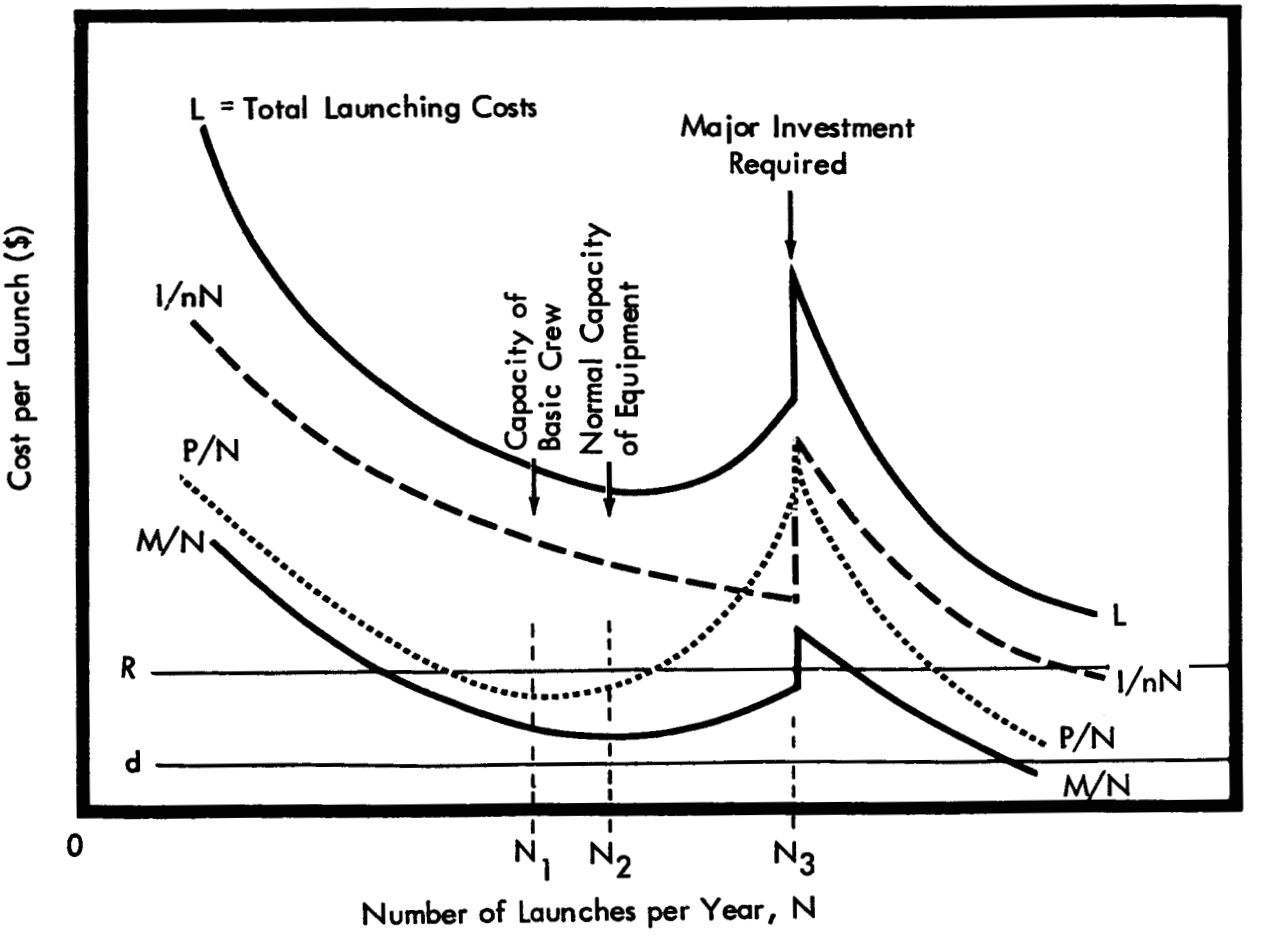

Cost per Launch ($)
L = Total Launching Costs
I/nN = Facilities Cost
R = Range Cost
P/N = Labor Costs
M/N = Maintenance Costs
d = Pad Repair Costs
0
Number of Launches per Year, N

FIGURE 9
Unit Launch Costs as a Function of Launching Rate
(Launch Rate Increases Beyond Basic Capabilities)



The behavior of per launch costs for a wide range of launch rates is shown in Figure 9. (Note: Curve for L is not drawn to scale.) As the number of yearly launches increases, the per launch cost, L, does not become asymptotic to some constant (minimum) value for the following reasons:

1. At some launch rate, say N_1, the capacity of the launch team will be exceeded, requiring additional labor costs attributed to increasing staff, overtime pay, multiple shifts, etc.

2. The annual maintenance costs will increase beyond some launch rate, N_2, since equipment will be taxed beyond normal capacity.

3. Perhaps most significant, the basic launch equipment will not be able to handle the load beyond some launch rate N_3, thus requiring a major increase in investment, e.g., for a second pad.

(2) Test Philosophy

In order to achieve a given number of successful launches per unit time, some number of actual launchings greater than the desired quantity must be planned for (and actually shot) depending upon the probability of failure, or failure rate, of the vehicle.

If we assume that upon delivery of a vehicle system, a basic acceptance test is the only testing performed, then the probability of failure of the mission objective, f_o, represents

the inherent manufactured capability. The actual number of launches, ℓ_a, will be related to the desired number, ℓ_d, as shown in Equation (5)

$$\ell_d \leq \ell_a \leq \ell_d/(1 - f_o) \tag{5}$$

(within an assumed confidence level).

For a vehicle system with a cost of \$V, the total cost of the number of desired successful launches, ℓ_d, is:

$$TV_d = V(\ell_a) + L\ell_a(\ell_a) \tag{6}$$

$$= \ell_a(V + L\ell_a) \tag{6a}$$

where L is computed from Equation (4).

Equation (6a) states that the total vehicle costs for some number of desired launches are equal to the actual number of launches required times the sum of the cost of a single vehicle plus the launch costs per vehicle based on the actual (or needed) launch rate.

The total vehicle costs per <u>successful</u> launch are:

$$TV = TV_d/\ell_d \tag{7}$$

$$TV = \frac{\ell_a (V + L_{\ell_a})}{\ell_d} \quad . \tag{7a}$$

From the a priori point of view, the actual number of launches, ℓ_a, will be equal to some number more than the desired number of launches. For a supposed failure probability, f_o, and with a confidence, a, ℓ_a may be derived from the binominal distribution:

$$a = \sum_{i=\ell_d}^{\ell_a} C^{i}_{i-\ell_d} f_o^{\,i-\ell_d} (1 - f_o)^{\ell_d} \tag{8}$$

where,

$$C^{i}_{i-\ell_d} = \frac{i!}{(i - \ell_d)\,!\,(\ell_d)\,!}$$

or using the Poisson approximation,

$$a = \sum_{i=\ell_d}^{\ell_a} \frac{e^{-if_o} (if_o)^{i-\ell_d}}{(i-\ell_d)!} \quad . \tag{8a}$$

For a $j\sigma$ confidence level

$$\ell_a \simeq \ell_d \left(1 + f_o + K_j \sqrt{\frac{f_o (1-f_o)}{\ell_a}}\right) \tag{9}$$

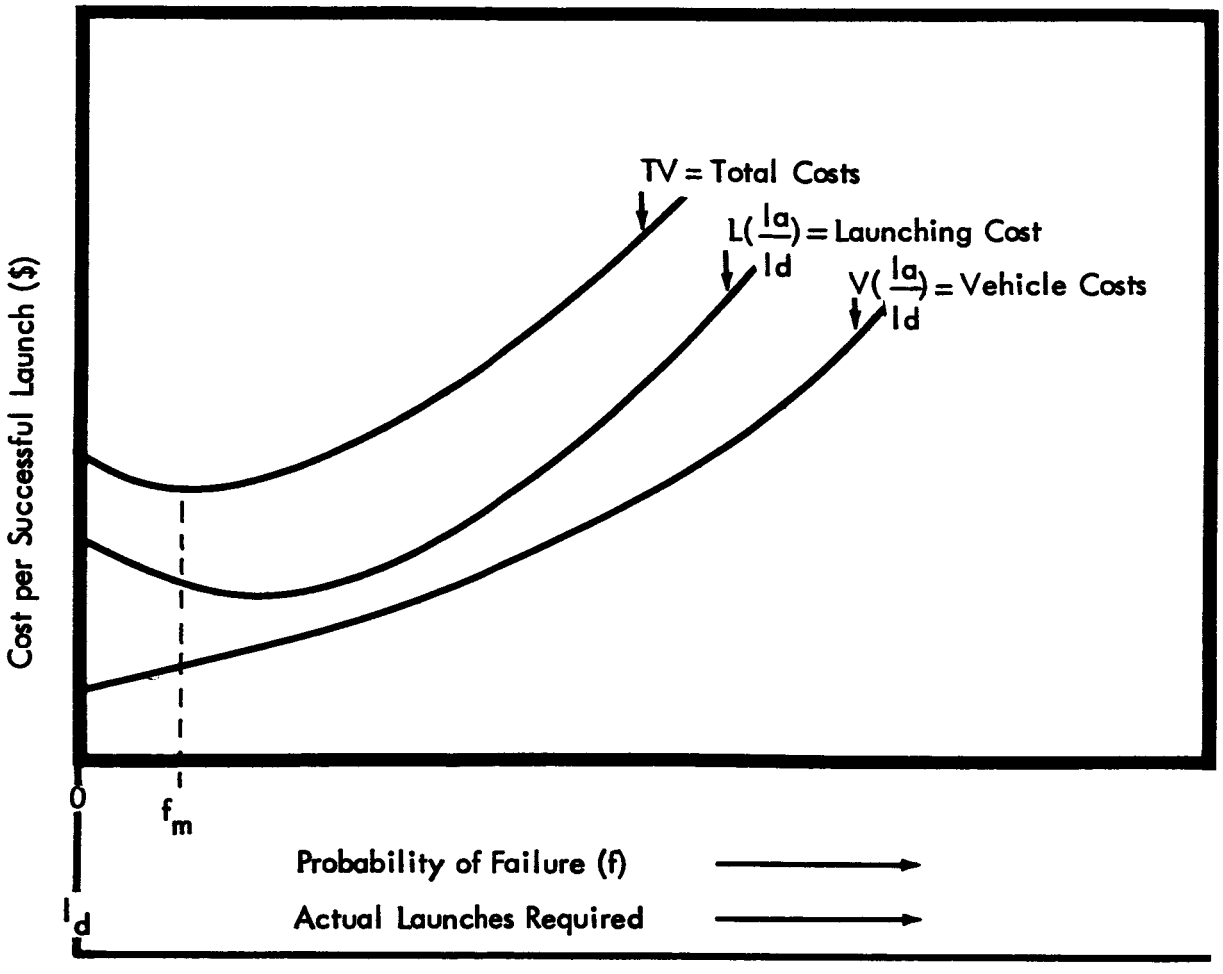
combining Equations (7a) and (9), we have

$$TV \simeq (V + L_{\ell_a}) \left(1 + f_o + K_j \sqrt{\frac{f_o (1 - f_o)}{\ell_a}}\right). \qquad (10)$$

Equation (10) can be conveniently solved using tables of the cumulative Poisson distribution.

Figure 10 (not drawn to scale) shows the behavior of total vehicle costs per successful launch (TV) as a function of failure probability for a given desired number of launches (ℓ_d) and a given, fixed vehicle cost. It is evident from this figure that there is a minimum total per launch cost at f_m, some optimum failure probability. Note that the launch rates are assumed to be within the basic equipment capacity as shown in Figure 9. Note also, that the minimum total cost per launch, TV, does not occur at a zero failure probability. It will be recalled, from Figures 8 or 9, that fewer required firings mean that the total launching costs have to be distributed to fewer vehicles, thus raising their cost burdens. As more vehicles are fired, their per vehicle launch cost decreases until the facilities become taxed, at which point the costs begin to rise. Note that if vehicle costs are very much higher than launch costs, or the launch

FIGURE 10
Variation of Costs with Failure Probability
(Desired Number of Launches Held
Constant, within Basic Equipment
Capacity of Figure 9)



facilities are operating at or near maximum, capacity, it is possible for the optimum failure probability to approach zero.

The addition of the payload to the cost picture does not change the basic behavior. Since the per successful launch costs for the paylaod operate in the same manner as the per successful launch costs of the vehicle, the total cost curve (TV) of Figure 10 would merely be displaced upward from the position shown and the saddle point would occur at a different value of failure probability. (Assuming that the payload cost is constant regardless of failure probability.)

A study of the effects of reducing payload costs as a function of expected success of the launch vehicle is outside the scope of this first analysis.

At this point, we can conclude that any investment in the vehicle or use of the facilities for testing in order to upgrade quality beyond the optimum level is wasteful. However, reducing vehicle quality and cost, and transferring the upgrading process to the launch facilities may be desirable under certain circumstances.

Suppose a vehicle system has a failure rate which is a function of a minimum investment in its manufacture. Improving this figure, that is, reducing the failure rate, can be achieved in one of two ways.

1. Further investments in the manufacture and reliability of the vehicles.

2. Use of the launch facilities for testing and upgrading the quality of the vehicle.

When the vehicle is upgraded at the factory, there is a direct cost associated with the process. However, using the launch facilities for this purpose poses a somewhat different problem.

When the launch facilities are used for a purpose other than launching, the primary impact is to reduce the potential launch rate. (Recall the discussion associated with the launch costs of Figures 8 and 9.) As more time is invested in non-launch activities, the potential launch rate may be so reduced that, even with the higher success probability, the facility will not handle the required launches. Figure 11 shows a possible situation.

The curve L represents launch costs as a function of number of launches per unit time as shown in Figure 9. To this, we add the cost of a vehicle as purchased resulting in L'. The resulting total cost per launch for this launch rate, ℓ_{a_1}, is S_1.

Suppose we wish to improve reliability by purchasing a better vehicle. Then, our costs would move up to curve L'', first to point (1) along the vertical line ℓ_{a_1}, but, because of the reduction in the number of launches needed because of better reliability, finally to point (2), at a lower launch rate ℓ_{a_2}. The per launch cost for this improvement is $S_2 - S_1$.

To improve the reliability the same amount (i.e., the amount necessary to lower the required launch rate from ℓ_{a_1} to ℓ_{a_2}) holding the vehicle costs constant but utilizing the the launch facilities to improve vehicle quality, curve L'_F results. Note that curve L'_F has its incremental point at a lower maximum launch rate because the facilities are being used for non-launch purposes. Also, the cost per launch has moved upward from the intersection of ℓ_{a_1}, with L' because more time and labor is expended per vehicle. In this example, the operating point at ℓ_{a_2} on curve L'_F gives rise to S'_2 as a

cost which is less than S_2. Thus, it would be more desirable to use the launch facilities for the desired reliability upgrading, than to improve on the vehicle manufactured quality.

The total cost for this launch program would be $S_2(\ell_{a_2})$ (the area within the rectangle, Figure 11), or $S_1(\ell_{a_1})$, or $S'_2(\ell_{a_2})$. The optimum choice is the smallest product.

We can now consider the effects upon the total costs of a program if investments are made in the launch facilities to improve turn-around time. If no transfer of the quality function takes place, then the launch rate will remain constant.

In Figure 12, L' is the cost of some sophistication level of launch facility, plus vehicle costs. L'_I indicates a more advanced launch facility with the same vehicle costs. Because the actual launch rate, ℓ_{a_1}, is well within the capacity of L', the additional capacity of L'_I provides no benefit to the program. Conversely, L'_L represents a launch facility of less capacity than that represented by L'. Under these conditions, total costs will be less, although turn-around time will be longer and the capacity of the system will be smaller.

FIGURE 11
Effect of Investment Policy upon Total Costs per Launch

Legend: ——L = Basic Launching Costs (Figure 9)
——L' = L + Cost of Vehicle
– – –L" = L + Cost of a more Reliable Vehicle
——L'_F = Total Cost Using Launch Facilities to Improve Reliability of Basic Vehicle of L'.

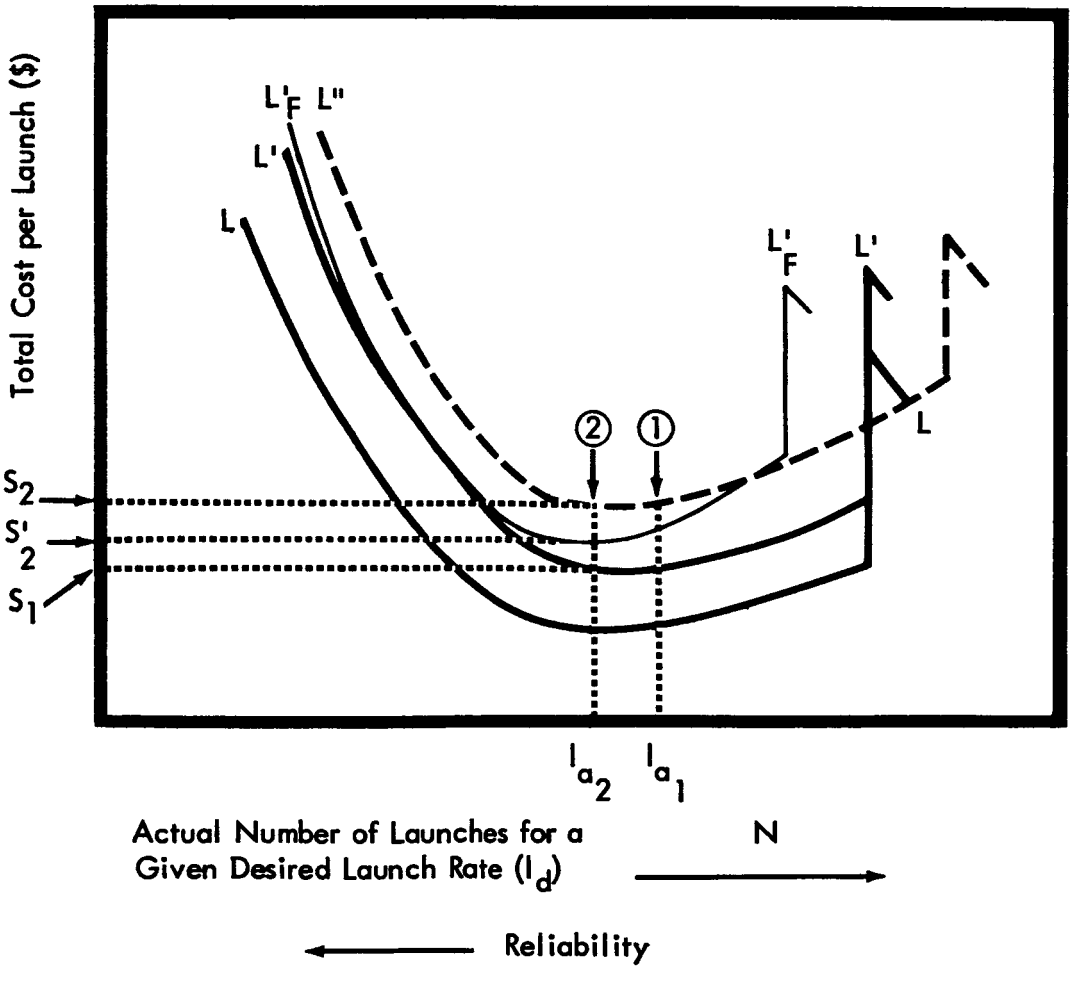
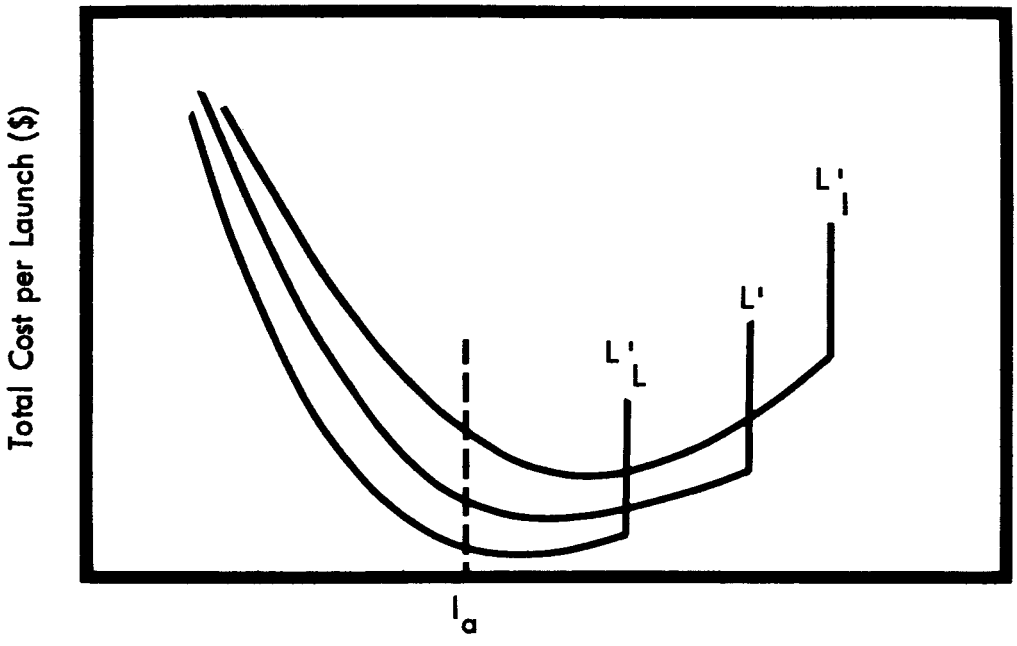


FIGURE 12
Effect of Turn-Around Time Upon Total Costs per Launch
(i.e.,the Effect of Improved Checkout Equipment, etc.)

Legend: L' = Basic Launching Costs plus Vehicle Cost
L'_I = Total Costs with Launching Facilities Improved to make Greater Capacity Possible
L'_L = Total Costs with Less Complex Launch Facilities Having Lower Capacity



In general, turn-around time and launch capacity cannot be considered independently of vehicle costs, reliability and desired launch rate. Figures 11 and 12 indicate that vehicle costs and launch facility costs can be represented by surfaces in a three dimensional coordinate system, the other coordinate being reliability and/or actual launch rate. Each surface (cut by a reliability plane) has a local minimum total cost, and the local minimums have a global minimum which represents the optimum trade-off between investments in vehicle manufacture and investments in launch facility capability.

The model developed above is quite analogous to the commuter whose train leaves at 8:00 a. m. and who, for independent reasons, must arise at 7:00 a. m. No investment in processes and intermediate transportation can improve his arrival time at the final destination. His optimum choice is to utilize the entire hour at least cost.

(3) Application to a General Program

If we assume that, regardless of the investment in the vehicle's quality, at least one operating test must be performed prior to launch and, if the launch rate is such that there would be idle time if the vehicle were erected, tested once, and

launched in the shortest possible time, then from the foregoing model with its basic assumptions concerning incremental facility investments and crew continuity we can conclude:

1. No investment should be made to improve vehicle quality to reduce launch facility use until the launch costs become incremental (i.e., until a substantial investment in additional facilities would be required to obtain the desired launching rate).

2. The facility should be utilized for as much of the final preparation and test as will fit between launch cost increments based upon desired launch rate.

3. Questions of facility turn-around time are meaningless between increments.

4. Investments in manufacturing should be reduced and transferred to facilities so long as the launch costs remain between increments.

5. Improvements in checkout equipment which reduce manpower and increase investments are not necessarily desirable.

6. For a program under development, an optimum distribution of vehicle and facility investments can be derived.

In order to utilize the above model for a particular program, specific cost and other data will be needed. Listed below are the necessary values:

1. Range cost per launch

2. Manpower costs per year

3. Desired launch rate per year

4. Investment in facilities

5. Maximum capacity of facilities and basic crew

6. Maintenance costs per year

7. Vehicle costs

8. Expected reliability

9. Reliability/cost relationships for the vehicle

10. Checkout and test equipment (at the launch site) cost/time relationships.

3. INFORMATION AND DATA REQUIRED

The information and data required to perform the intended study is extensive and of many types. The following summary is presented both as a partial checklist for later use, and as a further indication of the study scope.

(1) Vehicle Descriptive Information

1. System schematics and drawings

2. Training manuals and charts

3. Performance summaries

4. Vehicle model specifications

5. Schedule of documentation required of GD/A by contract

6. Same as item number 5 for Lockheed

7. Document Distribution List, Lewis R. C.

8. Other reports as required from list of materials stage contractors must supply to Government (see AF 58-1)

9. Selected component specifications

(2) Periodic Reports

1. Cognizant government agency (e. g., Lewis Lab.) monthly project reports

2. NASA "Flight Test Working Group" minutes of meetings

3. Contractor monthly progress reports

(3) Mission Information

1. Headquarters mission plans

2. History of mission launches

3. Payload descriptions from GSFC

4. Vehicle modifications required for specific missions

(4) Checkout and Test Procedures

1. Flow charts of factory, hangar and launch site operations, with time schedule

2. Test philosophy description

3. NASA methods of checking results

4. Detail test descriptions for factory, hangar and launch site operations

5. Test equipment descriptions

6. Countdown manual

7. Comparable materials for Air Force operations

8. Description of launch services contractors' duties

9. Data processing methods and records

(5) Integration Documentation

1. Reports and drawings exchanged by contractors

2. Description of integration contractor's duties

(6) Launch Preparation and Checkout Historical Data

1. Pad and hangar meeting minutes

2. Checkout test records of malfunctions, holds, etc.

3. GD/A and Lockheed Flight Test Evaluation Reports

4. Engineering modifications performed

5. Description of vehicle in configuration flown as compared to design

6. Actual and planned schedules

(7) Transportation

1. Methods stages are transported

2. Records on damage incurred during transportation

(8) Cost Data

1. NASA Headquarters planning costs

2. Launch pad, hangar and checkout equipment construction costs

3. Launch services costs as function of rate

4. Vehicle purchase costs

5. Integration and modification costs

6. Anticipated costs per launch

7. Actual costs per launch

8. Checkout procedures cost breakdown

9. Facilities maintenance costs

10. Launch hold time costs

11. Range costs

12. Expendables costs

(9) Organization and Management Information

1. Lewis Labs Organizations

   a. Atlas-Agena Project

   b. Field Representatives Branch at Lockheed, GD/A and SSD

2. Field Projects Branch at AMR

3. Operating charters of above organizations

4. USAF-NASA Memorandum of Agreement

5. Chart showing JPL, FPB, and Lewis Labs relationship on Agena. Same for GSFC

6. NASA Management Manual, Organization Charts: Project Mgt.. No.. 4-1-1; Launch Operations Center, No. 2-2-9.1.

7. AFMTC Test Operations Organization Chart for Lockheed, Launch Services Organization

8. Same as item 7, for GD/A

9. Air Force SSD organization charts:

   a. Deputy for Engineering, under Col. R. W. Hoffman, SSV

   b. S-01A, Space Projects Director, under Col. E. F. Blum

   c. SLV-II Director, Col. Marshall

10. Organization chart for Lockheed Missiles and Space Division, Space Programs Division, Medium Space Vehicles Program under E. P. Wheaton and Harold T. Luskin

11. Same as item 10, for GD/A.

(10) Contracts

1. Launch Services Contracts for GD/A

2. Same as item 1, for Lockheed

3. Technical Support Services work statement (Lockheed Proposal)

V. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations divide naturally into two groups, those which directly concern the Delta vehicle, and those which though derived from experience gained in studying Delta, apply primarily to the next parts of the study and to future programs. The conclusions and recommendations are therefore accordingly presented below.

A general conclusion is that it was well to have begun the study of space vehicle checkout, integration and launching with a very successful program, namely, the Delta project. Enough successful launches have been accomplished to supply, if not statistical rigor, at least practical assurance that the success of the program is genuine and that trends or lack of trends have meaning.

1. DELTA PROGRAM

(1) Reasons for Success

No single factor has been found which accounts for the success of the Delta program. The program success appears to stem from a combination of several factors: viz.; (a) diligence and care in the construction and checkout of the vehicle; (b) the

use of three proven stages, each of which has had a relatively large number of flights in configurations closely resembling those used on Delta; (c) the use of conventional, not highly sophisticated hardware; (d) a mission launch schedule that provides daily "windows" and relatively loose timing for launching; and (e) experienced personnel, both in program management and at the execution level, at AMR and the factory.

(2) External Constraints

The external constraints of mission scheduling, payload availability, and funding dominate the variations in the Delta program, not the performance of the technical tasks.

The number of payloads currently slated for launch on Delta, and the numbers launched in any year of the program to date, are below the capability of the launch pad, ground equipment, vehicle production, and other associated systems. Thus, launch rates or vehicle availability have not, as yet, limited the mission usefulness of Delta. For this reason, no order-of-magnitude improvements in the integration, checkout and launch procedures should be sought or expected, at this time. Prudent efforts should continue to improve product reliability and performance through the normal learning process of a well-managed

engineering development program, but it is the nature of such processes to produce continuous, percentage improvements, rather than large step-function improvements.

(3) Potential Launch Rate

The Delta launch facilities and associated checkout facilities are capable of attaining a launch frequency more than double the current rate. Considering only the time required for preparation on the launch pad, it is reasonable to expect that 24 vehicles could be launched per year, utilizing the two existing pads. This potential is based upon a planned average pad occupancy of 18 workdays (per the Douglas "typical" schedule), plus three workdays for launcher repair and checkout, and does not presume any improvements of equipment or procedures. It is also assumed that the additional experienced personnel can be secured as needed. This conclusion is supported by the experience on Delta 12 and 13, which were launched two weeks apart from the two launch pads. However, as noted in item (2) above, the increased launch rate is currently not required as there are not sufficient payloads planned for Delta to demand it.

(4) Pad Utilization

The 18 working days the Delta vehicle currently spends on the launching pad could be materially reduced through

improvements in vehicle quality as it leaves the factory, and by altering checkout procedures to perform more tasks off the pad. Again, as noted in item (2) above, the need does not currently exist for such an improvement, and therefore it is not recommended.

(5) Cost Per Launch

There is no doubt that the cost per launch of Delta could be reduced by cost-optimizing the number of launches per year. This action would also reduce the problems of managing the launch program and would improve launch reliability through improving personnel continuity and stability. This advantage would have to be balanced against the number and types of payloads. (The cost data analysis is presented in Volume II.)

(6) Launch Schedules

The Delta program, while very successful in orbiting spacecraft, has not been highly successful in launching on dates set far in advance. This is undoubtedly due, in part, to the non-critical nature of most of the Delta launch windows. If the Douglas "typical" schedule for checkout from pre-composite to launch is used as the criterion, and vehicles exceeding the Douglas prediction are considered late in being launched, close

to 75 per cent of the Delta launches would be rated as having missed their schedules. However, since the time required for checkout has shown a downward trend with increased experience, the Douglas "typical" schedule is now considered to provide a realistic plan for scheduling a launch, a fact which appears to be a direct function of launch crew experience. The present Delta AMR team is quite confident that, if required, they could hit a very narrow launch window, one only seconds in length. Given sufficient lead-time, their confidence may be justified.

(7) Improvements in Accomplishing Checkout

Some areas were isolated during this study in which improvements appear to be possible, if, in view of the over-all program considerations, they are demonstrated to be worthwhile. Three such areas and suggestions for their improvement follow:

1. Schedule slippage and unnecessary work at AMR could be alleviated by upgrading some of the weaker Delta subsystems. The first stage gyroscopes and some telemetering and electronic components have caused an excessive number of problems during checkout. Isolation of systems requiring improvement has not been a primary objective of this study; the Delta management is in

a superior position relative to such an effort and may know of other such items.

2. Incorporation of engineering improvements and mission modifications prior to shipment of the vehicle to AMR (prior even to pre-shipment checkout) would reduce the workload at AMR, including some of the extensive testing now required. Since vehicles now generally spend less total time at AMR prior to launching, than they did early in the program, this may now be quite feasible.

3. Malfunctions and sub-standard items have supplied the largest single cause of unscheduled work at AMR. More than half of all defects have been of types which can reasonably be assumed to have originated at the factory. Of such items, 90 per cent were of a relatively serious nature. Thus, one of the most obvious means to reduce the effort at AMR would be to improve the system for eliminating most of these faults prior to shipment of the vehicle.

(8) Observations Based on Unscheduled Activities Analysis

The following observations and conclusions were drawn from the tables and curves presented in Section III.2, "Unscheduled Activities Analysis":

1. The total number of unscheduled activities (U. A.) encountered during the checkout of a vehicle was not a function of the total time the vehicle spent at AMR (storage plus checkout), nor a function of the time spent between pre-composite and launch.

2. As the Delta program progressed, the total number of unscheduled activities displayed no significant trend. Malfunctions and items of sub-standard

quality tended to increase, while unscheduled modifications, development and learning problems, and the investigation of questionable items continue to cause modest numbers of unscheduled activities. The number of scheduling problems, engineering tests and investigations, and parts shortages were never great, and did not tend to increase or decrease.

3. No significant difference could be detected between the first and second stages as sources of U. A. The third stage has been relatively free of trouble.

4. Only 2.5 U. A. and only one critical problem arises, on the average, between T-1 day and launch. It therefore appears that the checkout procedures prior to this time accomplish their purpose quite well.

5. The combined U. A. caused by the control and guidance, electrical and electronic, and instrumentation and telemetering subsystems total approximately two-thirds of all of the U. A. encountered during checkout.

2. FUTURE STUDIES AND PROGRAMS

(1) Cost Per Launch

An easy to use, analytical cost model must be developed to aid in determining the cost per launch and in optimizing this cost for any vehicle program. Since no one vehicle will launch all payloads, consideration must also be given to optimizing the over-all mission and payload effectiveness of all of the

launch vehicles in use. The model must provide the means of evaluating when to build new test facilities, when it pays to improve checkout procedures, and what it costs to maintain excess launch capability.

On this latter point, the Delta program has been required to maintain a capability consistent with the launch schedule predicted from mission forecasts. In practice, the actual demand on this capacity has approximated one-half of the forecast. This discrepancy has been due, in part, to spacecraft slippage, and in part, to the fact that the success of the program has made a number of expected backup launches unnecessary. It is no part of the present study to evaluate or criticize the decisions which led to these discrepancies. It is a goal of this study to supply mission planners with a method for making realistic estimates of the costs of such discrepancies in order that these costs may be properly weighted in making future forecasts.

(2) Pad and Checkout Facility Utilization

Better pad utilization has not been clearly necessary in a space program which has two launch pads at its disposal,

and in which the shortest interval between launches called for by the schedule is of the order of two weeks. It is easy to visualize, however, mission requirements which would render this type of schedule unacceptable, and it is equally easy to see that in planning facilities for future programs, the cost of extra pad capacity must be balanced against the cost of reducing pad turn-around time. Tools for making these comparisons are also a principal goal of the present study.

(3) Launch Schedules

In performing future launch programs, means must be available to balance the constraints enforced by necessary launch rates, pad and checkout equipment availability, narrow launch windows (some of which may be rarely-occurring astronomical opportunities), and near-simultaneous launchings, and to determine the optimum cost balance of these and other factors. Virtually continual sophistication of the analytical model will undoubtedly be required.

REFERENCES

1. Delta Launch Vehicle, Douglas Document SM-43616, revised June 1963.

2. Project Delta, Third Stage Activities at AMR, (Douglas unnumbered document).

3. "Launcher Operations Schedule" - (Flight 20), June 25, 1963.

4. "Procedure T-6 Acceptance Test-Delta" Douglas Dwg. No. 7850920.

5. "Procedure T-3 Day All-Systems Test-Delta" Douglas Dwg. No. 1A16239.

6. Delta Countdown Manual, Douglas Aircraft Company, Inc., 20 February 1962; also Revisions #1 and #3 to Delta Countdown Manual dated 7 December 1962, as well as Revision #1 to Delta Countdown Manual dated 1 June 1963.

7. Project Delta 14 . . . Operations Summary, NASA - GSFC, 22 October 1962.

8. Project Delta 20 . . . Operations Summary, NASA - GSFC, 18 July 1963.

9. (1) "Agenda for Grid Area Acceptance Meeting" - Delta 11, 12, 13, 14, 15, 16, and 20.

   (2) "Grid Area Acceptance Meeting" (Minutes) - Delta 4, 5, 6, 7, 8, 9, and 10.

   (3) " . . . report of hangar activities on Missile 286" (Delta 5).

   (4) "Acceptance Agenda" - Delta 17.

10. (1) "Agenda - Launcher Acceptance Meeting" - Delta 13, 15, 16, 17.

(2) "Launcher Acceptance Test Meeting" - Delta 17.

(3) "Acceptance Test Status Meeting" (Minutes) - Delta 4, 5, 6, and 9.

(4) "Agenda - Acceptance Test Meeting" - Delta 7, 8, 9, 10, 11, and 19.

11. (1) "Pre-Countdown Meeting Agenda (T-1 Day)"- Delta 6.

(2) "Minutes of T-1 Day Pre-Countdown Meeting" - Delta 4.

(3) "Agenda for T-1 Day Meeting" - Delta 5, 11, 12, 14, and 15.

12. "Flight Flash Report" - Delta 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19.

13. "History" (segment of unidentified AMR report) - Delta 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18.

BIBLIOGRAPHY

1. AMR Instrumentation Handbook, Volumn I - Operational Systems; Technical Documentary Report No. MTC-TDR-63-1.

2. Douglas Organization Charts C 7.0-1, April '63, and IC 8.3-2, January 1963.

3. Delta 7 (Tiros D) Final Flight Report, Douglas report SM-41505.

4. Ground Support Equipment and Facility Modifications Required for Launch of Thrust Augmented Delta Vehicles from AMR, Douglas report SM-42859, February 1963.

5. Delta Ground Support Equipment, Second and Third Stages, Douglas report SM-43553, March 1963.

6. Model Specification, DSV-3B Delta Space Research Vehicle, Douglas Document DS-2325, Issue 2, 28 February 1963.

7. NASA - Industry Program Plans Conference, NASA SP-29, 1963.

8. Project Delta Terminal Count History, Revision 1, Field Projects Branch, GSFC, August 1963.

9. Project Delta Test Support Equipment, Douglas Document TU-24576, 1 January and 1 August 1960.

10. Spacecraft Operations at AMR, Safety Regulations and Documentation Requirements, NASA/GSFC Field Projects Branch, Cape Canaveral, 16 April 1963.